MAGYAR TUDOMÁNYOS AKADÉMIA
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INSTITUTE OF ECONOMICS
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MŰHELYTANULMÁNYOK **DISCUSSION PAPERS**

MT–**DP.** 2004/22

THE LAW OF TWO PRICES: TRADE COSTS AND RELATIVE PRICE VARIABILITY

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Institute of Economics
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Budapest

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The law of two prices: trade costs and relative price variability

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THE LAW OF TWO PRICES: TRADE COSTS AND RELATIVE PRICE VARIABILITY

BY MIKLÓS KOREN

Abstract

The paper investigates whether deviations from the law of one price can attributed to real factors, such as transportation and distribution costs. Even if trade is costly, the prices of a good at di.erent locations will be linked as long as the good is traded. Instead of the usual iceberg assumption, I model costly trade as a transportation sector that uses real resources with potentially different factor intensities than the production of the good.

First I use a latent factor model to see if distance specific ("transportation") and location specific ("retailing") factors can explain deviations from the law of one price across U.S. cities. For many products, these two factors explain 10-20% of all the variation in prices. The estimated transportation factor tends to move together with oil prices.

Next I derive the variance of relative prices at di.erent locations when the price of transportation is determined in general equilibrium. This variance is high if (i) the good is costly to transport and (ii) it is produced with different factor intensities than transportation. Preliminary empirical results suggest that goods similar to transportation in terms of factor intensity have indeed lower relative price variability. As these goods tend to be costly to ship, this helps resolve the puzzling finding of Engel and Rogers (2001) that less tradable goods have less volatile relative prices.

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MŰHELYTANULMÁNYOK DISCUSSION PAPERS

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KOREN MIKLÓS

A KÉT ÁR TÖRVÉNYE: KERESKEDELMI KÖLTSÉGEK ÉS A RELATÍV ÁRAK VÁLTOZÉKONYSÁGA

Összefoglalás

A dolgozat azt vizsgálja, hogy az egy ár törvényétől vett eltérések mennyiben tulajdoníthatók olyan reál-költségeknek, mint a szállítási és elosztási költségek. Még pozitív kereskedelmi költségek esetén is szigorú összefüggés van egyazon termék két különböző helyen fizetendő ára között. A szokásos "jéghegy-feltevés" helyett külön iparágként modellezem a szállítást, amely ugyanazokat a tényezőket használja, mint a termelés, de esetlegesen eltérő tényezőintenzitással.

Először egy faktor modell keretében megvizsgálom, hogy az Egyesült Államok városai közti áreltérések milyen mértékben magyarázhatóak távolságfüggő ("szállítás") vagy helyfüggő faktorokkal ("kiskereskedelem"). Ez a két faktor az áreltérések 10-20 százalékát magyarázza. A távolságfüggő faktor (amit a szállítás áraként értelmezhetünk) együtt mozog az olajárral.

Amennyiben a szállítás árát általános egyensúlyban határozzuk meg, abból levezethető két város relatív árainak változékonysága. Egy adott termék esetén ez a változékonyság akkor magas, ha (i) a termék drágán szállítható és (ii) a termék termelése eltérő tényezőket használ, mint a szállítása. Az előzetes empirikus eredmények megerősítik azt az állítást, hogy a szállításhoz hasonló tényező összetételű termékek relatív árának kisebb a varianciája. Mivel ezek tipikusan drágán szállítható termékek, az eredmény konzisztens Engel és Rogers (2001) meglepő eredményével, amely szerint a nehezen "kereskedhető" termékek relatív ára kevésbé ingadozik.

1. INTRODUCTION

The large discrepancy of prices at different locations has been a puzzle for international economists. Integrated markets should obey the "law of one price" (LOOP), that is, the same good should sell for the same price irrespective of location. In reality, they do not, which generated an enormous empirical literature documenting the patterns and causes of deviations from the LOOP.

This paper investigates whether trade costs can explain deviations from the LOOP (DLOOP). In particular, I ask how the cross-sectional and time-series patterns of DLOOP can be related to costs of transportation and retailing. Empirical studies on the DLOOP usually focus on (i) the cross-sectional dispersion of prices, or, in absence of actual price level, (ii) the time series volatility of relative price indices at different locations, and (iii) the speed of mean reversion in the DLOOP. As I argue later, they do so with little theoretical underpinning, assuming that more integrated markets (associated with lower trade costs) exhibit (i) lower price dispersion, (ii) less volatile relative price, and (iii) faster reversion to the LOOP. I show that the validity of these assumptions in general depends on the technology of transportation and retailing. In fact, empirical studies typically find bigger cross sectional dispersion of prices for goods that are costly to trade but fail to uncover such patterns for the time-series volatility of relative prices.

From a macroeconomic point of view, the DLOOP be formulated as the "purchasing power parity (PPP) puzzle," so coined by Rogo. (1996), who shows that deviations from PPP (i.e., real exchange rate fluctuations) are large and persistent. Neoclassical explanations that point to the relative price of tradable and nontradable goods (Balassa and Samuelson) have little hope for success since Engel (1999) has shown that this relative price explains very little of the U.S. real exchange rate: the bulk of the variability comes from fluctuation of the relative price of traded goods. This suggests that the law of one price may not even hold for individual goods.

In turn, a number of papers have looked at more disaggregate goods. Perhaps the most striking .nding is due to Engel and Rogers (1996), who look at the variability of the consumer price index of goods in different U.S. and Canadian cities. Even in such integrated economies, relative prices vary wildly, especially if the two locations under scrutiny are on different sides of the border. Engel and Rogers (1998) and (2001) provide further analysis of the issue. A puzzling finding is that nontraded goods have lower inter-city price variability then traded goods.

If data permits, it is useful to look at actual price levels of well defined goods instead of price indices of good categories. This is what Parsley and Wei (1996) do when they look at the prices of 51 products in 48 U.S. cities. They study the speed of mean reversion of DLOOP. Parsley and Wei (1997) take this approach to Japanese and U.S. data, again confirming that there is substantial variation of good prices across locations, an overwhelming majority of which is explained by the "border effect."

Similar chords are struck by Froot, Kim and Rogoff (1997), who use a historical dataset of various commodity prices in England and Holland to demonstrate that the variability of relative prices in the two countries have remained large in spite of the definite trends of trade integration.

What is common in these studies is that they are tacit about the theoretical determinants of relative price variability. Theory suggests that the existence of any relative price discrepancy indicates that markets are *segregated* but offers no further clues to assess the *magnitude* of this segregation.[1]

A possible reason for this silence is that existing theories *do not* predict relative price variability even in the case of large trade costs. Assume, for instance, that shipping a good from location i to location j entails a proportional transportation cost, τ. That is, one has to ship $(1+\tau)$ units of the good to ensure that 1 unit arrives. This is the famous "iceberg" assumption of Samuelson (1954). If the good produced at location i is sold at both locations then the following relationship pins down the relative price,

$$p_j = (1+\tau)p_i. \tag{1.1}$$

The good will be more expensive at location j because of the trade cost but the relative price at the two locations will always be $(1+\tau)$. That is, as long as good in question is traded, the iceberg assumption implies *no variability* in relative prices.

[1]An exception is the recent study by Bravo-Ortega and di Giovanni (2004), which uses the multicountry Ricardian model of Eaton and Kortum (2002) to theoretically pin down the volatility of the real exchange rate. However, they are concerned with the real exchange rate and not the relative price of tradable goods. Also, the channel they propose—the relative importance of nontraded goods—is different from ours.

What if the transport cost is so high that region j ceases to import the good from region i? Then p_j will be lower than $(1+\tau)p_i$ and (1.1) will only hold as an inequality. The reverse should also be true, that is, the price in region i cannot be higher than $(1+\tau)p_j$. This implies that the relative price is bounded between the following "arbitrage points,"

$$1/(1+\tau) \leq p_j/p_i \leq 1+\tau.$$

If transport costs comprise 4% of the value of the good, arbitrage prevents the relative price from being higher than 1.04 or lower than 0.96. The higher the proportional transport cost, the wider the potential range of relative prices. This offers an intuitive connection between trade costs and relative price variability that is often cited in empirical studies.[2]

Note, however, that both *strict* inequalities can only hold if the good is not traded at all, that is, if markets are completely segmented. Even if a small amount is shipped from region i to region j, the law of one price should still hold for "factory gate" prices.[3] We should observe imports of the good to region j at the upper bound of the no-arbitrage band, exports at the lower bound, and zero trade in between. The arbitrage band approach is hence inconsistent with the existence of persistent trade flows. Campa and Wolf (1997) also pointed this out, observing that there is no clear relationship between the volume of trade and the deviation from the law of one price.

This paper proposes an alternative approach to trade costs. I assume that transportation (as well as distribution and retail) uses the same factors of production as the final goods. It is important, though, that it may use different techniques, in particular, transportation may use different factors intensively than production. This means that the relative price of transportation is not necessarily constant as *assumed*

[2]See Anderson and van Wincoop (2003) for an excellent survey of the trade cost literature. Dumas (1992) offers an explicit derivation of these pricing points in a dynamic general equilibrium model.

[3]Here I make the assumption that goods are sold under perfect competition, that is, they are priced at marginal cost. Note that the same reasoning would apply if an imperfectly competitive supplier of the good applied the same markup in both regions. In most international macro models that use Dixit-Stiglitz-type monopolistic competition this will indeed be the case in equilibrium. Exploring how markups differ with destinations is an exciting question for future research.

in the iceberg model. However, the more similar the sector is to transportation, the better the iceberg model approximates trade costs.

As I show below, the two key determinants of relative price variability are (i) the magnitude of trade costs, and (ii) the similarity of producing the good to the transportation sector. In particular, relative prices are volatile if transport costs are high *and* the sector is sufficiently different from transportation. For example, fuel is relatively costly to transport (input-output tables of the U.S. show that around 9% of all fuel shipments is spent on transportation), yet the volatility of its inter-city relative price is among the lowest of all goods (see Table 4 in Engel and Rogers, 2001). This may be because transportation is highly fuel-intensive and the iceberg assumption (which, recall, implies no variability) approximates the shipping of fuels quite well.

Previous empirical studies failed to link relative price variability to trade costs. Even if more distant cities (countries) tend to have more volatile relative prices, the cross-sectoral patterns are contradicting this evidence: nontraded goods have lower volatility across U.S. cities than traded goods (Engel and Rogers, 2001). I show that this counterintuitive finding is the result of an omitted variable bias. Since transportation uses similar factors as nontraded goods (especially if we define transportation broadly to include wholesale and retail trade), the failure to account for similarity to transportation makes nontraded goods look less costly to trade. Controlling for both similarity and transport costs overturns this result and shows that high transport costs do lead to more price variability.

A number of recent studies in international macroeconomics have abandoned the traditional iceberg cost approach to analyze relative prices. Bergin and Glick (2004) work with heterogeneous transport margins across goods. The sets of traded and nontraded goods will then endogenously respond to price fluctuations. This causes the *average transport margin* for traded goods to fluctuate with domestic prices, generating additional fluctuations in the real exchange rate. In contrast to their approach, in my model the transport margin fluctuates with changes in the relative price of transportation. This channel is probably more important than changes in the set of traded goods over short horizons. Ghironi and Melitz (2003) focus on the fixed cost of entering export markets and firm heterogeneity. The real exchange rate in their framework depends the set of firms that engage in exports, also likely to change only over long horizons.

The rest of the paper is organized as follows. First I introduce a partial equilibrium exercise of decomposing deviations from the law of one price into transportation costs and local distribution costs. Second, I relate these two trade costs to the prices of tradable goods in a general equilibrium framework by comparing the factor intensities of sectors.

2. Trade Costs and Deviations from the Law of One Price

Take a single tradable product g produced and sold at two locations, i and j. Let c_{git} denote the producer price (marginal cost) of the good at location i at time t, $\tau_g d_{ij}^{\gamma}$ the amount of transportation (in tonmiles, say) required to move the good between the two locations (where d_{ij} is the distance between the two locations), λ_t the price of transportation, and μ_g the amount of distribution (e.g., in units of retail space and labor hours) and r_{it} the price of distribution of at location i. Suppose location i is a net exporter of the good. In this case, the consumer prices of the good at the two locations are

$$p_{git} = c_{git} + \mu_g r_{it},$$
$$p_{gjt} = c_{gjt} + \mu_g r_{jt} = c_{git} \pm \tau_g d_{ij}^{\gamma} \lambda_t + \mu_g r_{jt},$$

and the $\pm$ sign indicates an addition for goods exported from region i to j and a substraction otherwise.

The absolute deviation from the law of one price is hence

$$|p_{gjt} - p_{git}| = \tau_g d_{ij}^{\gamma} \lambda_t + \mu_g |r_{jt} - r_{it}|.$$

The two factors behind the deviation from the law of one price are shipping costs and relative retail costs. First I try to identify these two types of costs in the data to see how much of the deviations they explain. The key problem is that none of these costs is observable (though imperfect proxies may exist). I will hence treat them as unobserved factors in a latent factor model. The assumptions that identify these factors are:

(1) Total transport costs of good g between regions i and j only depend on the distance between the two regions. In particular, they do not depend on the identities of the regions.

(2) The price of transportation (λ_t) is common across all goods and regions. (Later I will allow for different modes of transportation varying with the good and distance, as can be deduced from the Commodity Flow Survey.)
(3) Distribution costs affect good g to the same extent in all regions.
(4) The price of distribution (r_{it}) is common to all goods within a region.

However, these are insufficient to separately identify the transport (distance-specific) and the retail (location-specific) factors in any cross section of cities. The reason is that the following are observationally equivalent: (i) transportation becomes more expensive, (ii) retailing becoming more expensive proportionally to distance to the benchmark city. The additional identification restriction I use is that in any comparison to the benchmark city there are as many "exported" products as "imported" products. (See study on European real exchange rates.) This is an ad hoc assumption to separate the impact of distance- and location-specific factors. However, it does not affect the estimation of the *joint impact* of these factors. I will work out an N-region version of the model later and use trade data from the Commodity Flow Survey.

3. Trade Costs in General Equilibrium

Let us turn to how the price of transportation is determined in general equilibrium. (I omit retailing in this section for ease of exposition.)

Consider the following $2 \times 2 \times 2$ model. Country 1 exports good 1, imports good 2.[4] Technologies are CRS and the same across countries. There are three sectors: good 1 with cost function $c_1(w_{.1}, w_{.2})$, good 2 with cost function $c_2(w_{.1}, w_{.2})$ and freight transportation with cost function $c_0(w_{.1}, w_{.2})$.[5] Factor prices may differ in the two countries, the dots in the subscript then must be replace by an index of the given country. One unit of transportation is used for every unit of exports and every unit of imports. (This symmetry could be easily broken.)

[4] I use the word "country" interchangably with "region."

[5] Transportation can be interpreted broadly to include any activity that is needed to export and import goods. We assume that these activities exhibit constant returns to scale so their marginal cost is constant.

Factors are mobile within a country but immobile across countries. This ensures that factor prices are equal across sectors within a country. This will pin down the relative prices of goods. Intuitively, if there are as many traded goods as factors, then factor rewards are determined by the goods prices. These factor prices then determine the relative price of transportation. In general equilibrium, of course, these effects take place simultaneously.

Consumers derive utility from both goods but do not care about the locality of the good. (A home bias could be easily built in by just indexing goods produced in the two countries separately.) Price fluctuations are driven by demand shocks, that is, the marginal utility of consuming good i in country h is subject to taste shock e_{hi}:

$$\mathcal{U}_1 = u_1(c_{11}/e_{11}, c_{12}/e_{12}), \tag{3.1}$$

$$\mathcal{U}_2 = u_2(c_{21}/e_{21}, c_{22}/e_{22}). \tag{3.2}$$

For now I make no assumptions about the joint distribution of taste shocks across goods and countries. Also, utilities need not be identical or homothetic.

The world good prices relate to the domestic prices as follows.

$$p_{11} = p_{w1} - c_0(w_{11}, w_{12}) \tag{3.3}$$

$$p_{12} = p_{w2} + c_0(w_{11}, w_{12}) \tag{3.4}$$

$$p_{21} = p_{w1} + c_0(w_{21}, w_{22}) \tag{3.5}$$

$$p_{22} = p_{w2} - c_0(w_{21}, w_{22}). \tag{3.6}$$

Note that world prices would only be observable in the "ether" between the two countries but I keep referring to them for ease of exposition.

As long as we are in the interior of the cone of specialization, both countries produce both goods and domestic consumer prices are equal to the marginal cost of production,

$$p_{js} = c_s(w_{j1}, w_{j2}). \tag{3.7}$$

The rest of the equilibrium conditions relate quantities demanded to quantities supplied and enforce the resource constraints within countries. As long as production remains within the cone of specialization, these conditions have no bearing price changes hence I omit them for brevity. Note, however, that if demand shocks are large, they may induce complete specialization, that is, a country could stop producing a good. This would break down the equalization of the price and the marginal cost of that good. Nevertheless, such drastic changes in the patterns of specialization are only likely to occur over the long run.

Market clearing requires the equalization of world prices, hence

$$c_1(w_{11}, w_{12}) + c_0(w_{11}, w_{12}) = c_1(w_{21}, w_{22}) - c_0(w_{21}, w_{22}), \tag{3.8}$$

$$c_2(w_{11}, w_{12}) - c_0(w_{11}, w_{12}) = c_2(w_{21}, w_{22}) + c_0(w_{21}, w_{22}). \tag{3.9}$$

Log-differentiating ($\hat{x}$ denotes $\mathrm{dln}\, x$),

$$\frac{1}{1+\tau_{11}}(\theta_{11}\hat{w}_{11} + \theta_{12}\hat{w}_{12}) + \frac{\tau_{11}}{1+\tau_{11}}(t_1\hat{w}_{11} + t_2\hat{w}_{12}) = \frac{1}{1-\tau_{21}}(\theta_{11}\hat{w}_{21} + \theta_{12}\hat{w}_{22}) - \frac{\tau_{21}}{1-\tau_{21}}(t_1\hat{w}_{21} - t_2\hat{w}_{22}), \tag{3.10}$$

$$\frac{1}{1-\tau_{12}}(\theta_{21}\hat{w}_{11} + \theta_{22}\hat{w}_{12}) - \frac{\tau_{12}}{1-\tau_{12}}(t_1\hat{w}_{11} - t_2\hat{w}_{12}) = \frac{1}{1+\tau_{22}}(\theta_{21}\hat{w}_{21} + \theta_{22}\hat{w}_{22}) + \frac{\tau_{22}}{1+\tau_{22}}(t_1\hat{w}_{21} + t_2\hat{w}_{22}), \tag{3.11}$$

where θ_{ij} denotes the share of factor j in producing good i, t_j is the share of factor j used in transportation, and τ_{ij} is the fraction of the consumer price of good j spent on transportation in country i.

Adopting straightforward vector-matrix notations (which then generalize the framework for the N-good case),

$$\hat{\mathbf{p}}_w = [(\mathbf{I} - \mathbf{\Lambda}_1)\mathbf{\Theta} + \mathbf{\Lambda}_1\mathbf{T}]\hat{\mathbf{w}}_1 = [(\mathbf{I} - \mathbf{\Lambda}_2)\mathbf{\Theta} + \mathbf{\Lambda}_2\mathbf{T}]\hat{\mathbf{w}}_2, \tag{3.12}$$

where $\mathbf{\Lambda}_i$ is the diagonal matrix containing the share of transportation costs (or, in other words, the deviation of world prices from domestic prices) in the two sectors in country i (with a positive entry for exports and a negative for imports), $\mathbf{\Theta}$ is the input usage matrix in production and $\mathbf{T}$ is the input usage in transportation.

With these notations, we can express consumer prices from factor prices as

$$\hat{\mathbf{p}}_i = \mathbf{\Theta}\hat{\mathbf{w}}_i. \tag{3.13}$$

In absence of transportation costs ($\mathbf{\Lambda}_1 = \mathbf{\Lambda}_2 = \mathbf{0}$), the relationship among factor prices becomes

$$\mathbf{\Theta}\hat{\mathbf{w}}_1 = \mathbf{\Theta}\hat{\mathbf{w}}_2, \tag{3.14}$$

which implies factor price equalization,

$$\hat{\mathbf{w}}_1 = \hat{\mathbf{w}}_2, \tag{3.15}$$

provided that $\mathbf{\Theta}$ is non-singular, i.e., the two goods use the factors with different intensities.

Another special case results if we assume that shipping good i requires the same factor intensities as producing good i. This is the usual assumption of iceberg trade costs: transportation uses up a fraction τ of the good shipped. With our notation, this case can be formulated as

$$\mathbf{T} = \mathbf{\Theta}, \tag{3.16}$$

$$\mathbf{\Theta}\hat{\mathbf{w}}_1 = \mathbf{\Theta}\hat{\mathbf{w}}_2, \tag{3.17}$$

$$\hat{\mathbf{p}}_1 = \hat{\mathbf{p}}_2. \tag{3.18}$$

That is, the percentage change of consumer prices is identical in the two countries even with iceberg transport costs. Note that the *level* of prices will generally be different, but the prices in the two locations will move in parallel. This property makes the iceberg cost model unsuitable to analyze questions such as real exchange rate and terms of trade volatility. It is also unclear how such a model can justify a relative price based approach to "border effects" (e.g. Engel and Rogers, 1996; Parsley and Wei, 2001, Kim, Froot and Rogoff, 2002).

Modelling the transportation sector explicitly allows for fluctuations in the relative price if transportation uses different factors intensively than the export and import sectors.

Proposition 3.1 (The Law of Two Prices)**.** *We can express domestic price relative to world prices as*

$$\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_w = \mathbf{\Lambda}_1(\mathbf{I} - \mathbf{T}\mathbf{\Theta}^{-1})\hat{\mathbf{p}}_1. \tag{3.19}$$

In the 2×2 case, the vector of relative prices can be written as

$$\hat{\mathbf{p}}_1 - \hat{\mathbf{p}}_w = \frac{1}{\theta_{11} - \theta_{21}} \begin{bmatrix} \lambda_1(\theta_{11} - t_{11}) & -\lambda_1(\theta_{11} - t_{11}) \\ -\lambda_2(\theta_{21} - t_{21}) & \lambda_2(\theta_{21} - t_{21}) \end{bmatrix} \hat{\mathbf{p}}_1, \tag{3.20}$$

where θ_{i1} is the share of input 1 in the production of good i (the first element of the ith row of $\mathbf{\Theta}$), and $\lambda_1 \equiv \tau_{11}/(1+\tau_{11})$ is the share of total transportation costs in the consumer price of good 1 (λ_2 is defined similarly).

When is the relative price of good 1 unresponsive to demand shocks? If either $\lambda_1 = 0$, that is, if there are no transport costs, or $\theta_{11} = t_{11}$, that is, if shipping works with the exact same technology as production of good 1 (iceberg costs). In general, however, demand shocks do change the relative price of goods across regions.

Consider the more general case with multiple goods and factors. (I still assume that the number of traded goods and immobile factors are the same.) For each sector s define the $1 \times N$ vector

$$\mathbf{t}_s \equiv \mathbf{T}_s \mathbf{\Theta}^{-1}, \tag{3.21}$$

where $\mathbf{T}_s$ is the sth row of the matrix $\mathbf{T}$, listing the factor intensities of transportation required for sector s. This vector $\mathbf{t}_s$ measures the similarity of transportation to each of the sectors in terms of factor intensities. To see this, rewrite (3.21) as

$$\mathbf{t}_s = \mathbf{T}_s \mathbf{\Theta}'(\mathbf{\Theta}\mathbf{\Theta}')^{-1},$$

that is, we obtain $\mathbf{t}_s$ by regressing the transportation factor intensities on the sectoral factor intensities. Hence if a sector uses similar factors as transportation, its corresponding entry in $\mathbf{t}_s$ is high (at the extreme, for identical factor intensities, the similarity measure is 1). Note that, by the properties of $\mathbf{\Theta}$ and $\mathbf{T}$, the components of $\mathbf{t}_s$ sum to 1.

We can then write the rows of (3.19) as follows,

$$\hat{p}_{1s} - \hat{p}_{ws} = \lambda_s(\hat{p}_{1s} - \mathbf{t}_s \hat{\mathbf{p}}_1). \tag{3.22}$$

Suppose that demand shocks in country 1 have a common and an idiosyncratic component,

$$\hat{p}_{1s} = u_1 + \varepsilon_{1s}, \tag{3.23}$$

with $\mathrm{Var}(\varepsilon_{1s}) \equiv \sigma_s^2$ and $\mathrm{Cov}(\varepsilon_{1s}, \varepsilon_{1s'}) \equiv 0$. Since the elements of $\mathbf{t}_s$ add up to one, the common demand shock will not affect the relative prices in the two regions.[6]

$$\hat{p}_{1s} - \hat{p}_{ws} = \lambda_s \left(\varepsilon_{1s} - \sum_{i=1}^{N} t_{si} \varepsilon_{1i} \right) \tag{3.24}$$

The variance of the relative price of good s is then

$$\mathrm{Var}(\hat{p}_{1s} - \hat{p}_{ws}) = \lambda_s^2 \left[(1 - 2t_{ss})\sigma_s^2 + \sum_{i=1}^{N} t_{si}^2 \sigma_i^2 \right]. \tag{3.25}$$

The first term measures the magnitude of trade costs. In general, higher trade costs lead to higher relative price volatility. The second term reflects the impact of idiosyncratic demand shocks on volatility. The contribution of these shocks to volatility depends on the sector's similarity to transportation. If a sector is less similar to transportation (t_{ss} is low), demand shocks have more of an impact on the price of the good relative to transportation and hence on the relative price in the two regions. The last term is a weighted average of demand shocks which does not vary across sectors.

4. Estimations

4.1. **Data.** In the two empirical exercises I use data on consumer prices in several U.S. cities. The first dataset comes from Parsley and Wei (1996) and includes retail prices (in current dollars) of 51 well-defined goods in 48 American cities collected by the American Chamber of Commerce. The goods include durable and perishable goods as well as services. See Appendix for the exact definition of the goods. The data is quarterly running from 1975:1 to 1992:4.

The second dataset comes from Engel and Rogers (2001), including monthly data on consumer price indices for 48 disaggregate categories in 28 U.S. cities. I match each good with its corresponding SIC87 sector and use the 1999 input-output tables to determine the input usage and transportation margins of these sectors. The index of *similarity to transportation* is calculated using the intermediate input shares.[7]

[6] Intuitively, if there are no relative price changes then relative factors do not change, either, so transport margins remain fixed.

[7] The theory would require factor input shares, which are harder to obtain. Work is in progress with calculating these shares using the 1997 Annual Survey of Manufactures from the Economic Census.

At a later stage, I will relate DLOOP to trade flows, using the 1997 Commodity Flow Survey, which contains state-to-state shipments in 43 good categories.

All prices are deflated by the overall urban CPI for the U.S. Additional data include pairwise driving distances between cities (from `http://mapquest.com`) and the per barrel price of West Texas Intermediate oil.

4.2. **Estimating the Latent Factor Model.** Generally speaking, I first run year-by-year cross sectional regressions to uncover the distance- and location-specific factors and then run time-series regression for each of the goods to estimate the factor loading of the good on these two factors.

Note that, by choice of units of retail and units of transportation, we can normalize both $\sum_{g=1}^{G}\mu_g/G$ and $\sum_{g=1}^{G}\tau_g/G$ to unity. Hence,

$$\frac{1}{G}\sum_{g=1}^{G}|p_{gjt}-p_{git}| = d_{ij}^{\gamma}\lambda_t + |r_{jt}-r_{it}|.$$

By our identification assumption the set of export goods exactly counterweights the set of import goods, so levels of "CPI"[8] in two cities only reflect the differences in the retail margin:

$$\frac{1}{G}\sum_{g=1}^{G}(p_{gjt}-p_{git}) = r_{jt}-r_{it}. \tag{4.1}$$

Once the retail factors have been obtained, I subtract them from the consumer price and regress the resulting price gap on distance to obtain the transportation factor, λ_t:

$$\frac{1}{G}\sum_{g=1}^{G}|(p_{gjt}-p_{git})-(r_{jt}-r_{it})| = d_{ij}^{\gamma}\lambda_t. \tag{4.2}$$

The parameter γ is taken from Hummels (2001) to be 0.25.[9] This says that transportation costs only mildly rise with distance. For example,

[8] I calculate the average consumer price by first normalizing all the good prices by their 1990 New Orleans prices and then taking a simple arithmetic average. This ensures that my consumer price index is not dominated by any particular good. Unfortunately, this requires a balanced panel of products and cities, limiting the data to 1980–1992.

[9] Alternatively, one could estimate it using nonlinear techniques.

shipping a good from New Orleans to New York city (1,176 miles) is 39% more expensive than shipping it to Houston TX (311 miles).

Figure 1 shows the time series of the bandpass-filtered transportation factor.[10] Because the BP filter gets rid of the first and last 6 quarters, and the retail factor can only be estimated for the end of the sample, I also plot an alternative retail factor, estimated without controlling for retail differences in Figure 2.

The factor can be best interpreted as the price of transportation. As a comparison, I also include the BP-filtered real price of WTI oil in both graphs. (All time series are normalized to have zero mean and unitary standard deviation.) The comovement between both transportation factors and the oil price is surprisingly close at the business-cycle frequency. Even though there may be some phase shift with the simpler factor (`factor2`), both factors math the overall trends, the troughs and booms of the oil price.

Next I estimate the factor loadings of each good and look at how much of the total price variation is explained by these two trade factors. This can be carried out in two ways, using either the cross sectional or the time series variation in deviations from the law of one price. In both cases, the two factors explain a substantial fraction of variation in the DLOOP for many goods. The cross sectional (within-year) R^2 ranges from 0.01 to 0.34 with an average of 0.11. The time-series (within-city) R^2 ranges from 0 to 0.14 with an average of 0.03. For highly traded products such as canned food, vegetables, meat products, household supplies etc. the fraction of variance is consistently higher in both dimensions.

Table X reports the factor loadings of the products. As the units of products differ (though all product prices are converted to 1990 New Orleans dollars, it is clear that \$1 of liquor does not necessarily require the same amount of transportation and retailing as \$1 of eggs), it is not meaningful to compare the factor loadings directly across products. I therefore calculate the *relative importance of transportation* as $\tau_g/(\tau_g + \mu_g)$, which is invariant to unit of measurement problems.

[10] I only look at business-cycle frequencies (between 6 and 32 quarters) because (i) the factor is probably estimated with an error and (ii) the relevant adjustments occur at this horizon.

The table lists the products in declining importance of transportation. Overall, traded products tend to be at the top of the list while nontraded service prices tend to be more retail than transport intensive (with some exceptions).

4.3. **Similarity to Transportation and Relative Price Variability.** Next I look at whether the time-series variation in the DLOOP is related to similarity of the sector to transportation as predicted by the model. I use the monthly CPI data of Engel and Rogers (2001) (see above).

Similarity to transportation is calculated from the use tables of the 1999 Input Output Accounts. Transportation is defined to include Motor freight and warehousing, Rail, Water and Air Transportation. The IO tables also list the transportation margins of each of the sectors (the fraction of total shipments spent on transportation), which I use as a measure of tradability.[11]

I calculate the time series variation in the DLOOP for each good category and each city pair in three ways. First I regress the (log differenced) price index in city 1 on the price index in city 2. If the LOOP holds, the coefficient of this regression should be one. I use $(\beta - 1)^2$ as a measure of the time-series deviation from the LOOP. Second, I take the simple correlation of price changes in the two cities. Third, I divide the variance of the relative price change by the variance of price changes in city 2.[12]

Table X reports the results of simply correlating these measures with distance, the transport margin of the good and its similarity to transportation. According to all three measures, the DLOOP is more volatile (and the correlation is lower) if the cities are farther apart. This is in line with the evidence of Engel and Rogers (1996), (2000), (2001). At the same time, the prices goods with a higher transport margin tend to move closer together. This is the puzzling finding of Engel and Rogers (2001). When we control for the sector's similarity to transportation, we see that goods similar to transportation (closer to the

[11]This obviously underestimates the effective margin since products with a high margin are not traded.

[12]Some goods have simply more volatile demand so it is useful to scale by the overall volatility of the good's price.

iceberg assumptions) exhibit lower DLOOP variability. Moreover, the coefficient on the transport margin of products attains the "right" sign (if marginally significant). That is, given the same degree of similarity, goods that are costlier to trade have more volatile DLOOP. This pattern was hidden because similarity and transport margin are positively correlated.

5. Conclusions

The paper investigates whether deviations from the law of one price can attributed to real factors, such as transportation and distribution costs. Instead of the usual iceberg assumption, I model costly trade as a transportation sector that uses real resources with potentially different factor intensities than the production of the good.

A latent factor model analysis shows that distance specific ("transportation") and location specific ("retailing") factors can explain 10-20 percent of the deviations from the law of one price across U.S. cities.

When the price of transportation is determined in general equilibrium, the variance of relative prices at different locations is high if (i) the good is costly to transport *and* (ii) it is produced with different factor intensities than transportation. Preliminary empirical results suggest that goods similar to transportation in terms of factor intensity have indeed lower relative price variability. As these goods tend to be costly to ship, this helps resolve the puzzling finding of Engel and Rogers (2001) that less tradable goods have less volatile relative prices.

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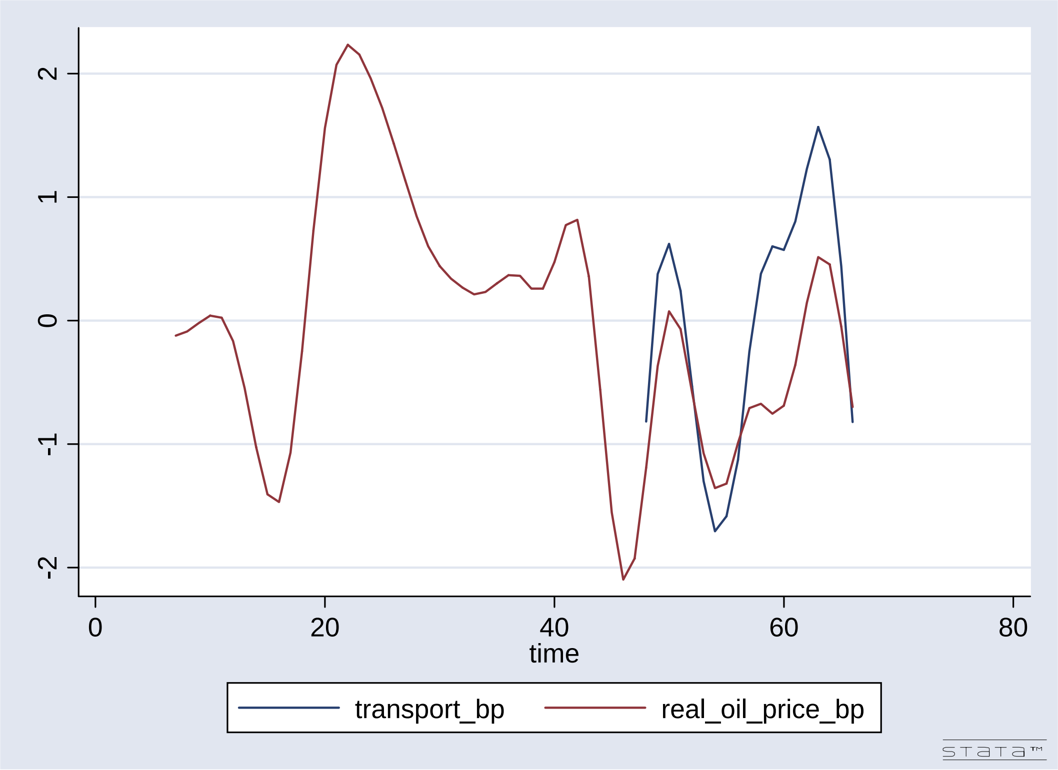
Appendix: Descriptions of Commodities Included

Item	Date added	Description
Appliance repair	75.1	Service call excluding parts color TV (75.1–79.1); Washing machine (79.2–92.4)
Aspirin	82.2	Bayer brand, 100 tablets, bottle 325 mg tablets (82.2–92.4)
Auto maintenance	79.2	Average price to balance two front wheels (79.2–84.1); average price to balance one front wheel (84.2–88.3); average price to computer or spin balance one front wheel (88.4–92.4)
Baby food	75.1	Jar 4½ oz. strained vegetables
Bacon	75.1	Pound of national brands
Bananas	75.1	Pound
Beauty salon	82.2	Woman's visit, shampoo, trim, and blow-dry
Beer	82.2	6 pack, 12 oz. containers, excluding deposit, Miller Lite or Budweiser
Bowling	75.1	Price per line evening price
Bread	75.1	24 oz. (75.1–80.2); 20 oz. (80.3–92.4)
Cheese	82.2	Parmesan, grated 8 oz. canister, Kraft
Cigarettes	75.1	Carton Winston king-size
Coffee	75.1	2 lbs. (75.1–80.2); 1 lb. (80.3–88.3); 13 oz. (88.4–92.4); Maxwell House, Hills Brothers, or Folgers
Corn flakes	79.2	12 oz. Kellogg's or Post Toasties (79.2–80.3); 18 oz. (80.4–92.4)
Dentist	75.1	Office visit, teeth cleaning and inspection, no X-ray or fluoride treatment

Item	Date added	Description
Doctor	75.1	Office visit, general practitioner routine exam of existing patient
Dry cleaning	75.1	Man's two-piece suit
Eggs	75.1	One dozen large grade A
Fried chicken	82.2	Breast and drumstick (82.2–83.4), thigh and drumstick (84.1–92.4), Church's, or Kentucky Fried Chicken if available
Frozen corn	84.1	Frozen, whole kernel, 10 oz. package
Game	82.2	Monopoly, standard (No. 9) edition
Ground beef	75.1	lb.; or hamburger
Hospital room	75.1	Semiprivate cost per day
Jeans	82.2	Levi's straight leg, sizes 28/30 to 34/36 (82.2–87.4), Levi's 501 (88.1–91.3); Levi's 505s or 501s (91.4–92.4)
Lettuce	75.1	Each
Liquor	75.1	750 ml. bottle Seagram's 7 Crown (75.1–88.3); J&B scotch (88.4–92.4)
Man's haircut	75.1	No styling
Man's shirt	82.2	Arrow or Van Heusen, white, long sleeve, cotton/polyester blend (82.2–83.4); sizes 15/32 to 16/34 (89.1–89.3); Arrow, Enro, Van Heusen, J. C. Penney, cotton/polyester (at least 55% cotton) long sleeves (89.4–92.4)
Margarine	75.1	Pound
McDonald's	82.2	½ lb. patty (82.2–83.2); ¼ lb. patty with cheese, pickle, onion, mustard, catsup (83.3–92.4)
Milk	75.1	½ gal. carton
Movie	75.1	First-run indoor evening price
Canned orange juice	75.1	6 oz. can (75.1–85.4); 12 oz. can (86.1–92.4)
Canned peaches	75.1	#2 ½ can approx 29 oz. (75.1–85.4); 29 oz. (86.1–92.4); Del Monte or Libby's halves or slices
Pizza	82.2	12″–13″ thin crust, regular cheese, Pizza Hut or Pizza Inn, where available
Potatoes	75.1	10 lbs. white or red
Shampoo	82.2	11 oz. container Johnson's (82.2–88.3); 15 oz. bottle (88.4–89.3); 11 oz. (89.4–90.4); 15 oz. bottle (91.1); 11 oz. bottle (91.2); 15 oz. bottle Alberto VO5 (91.3–92.4)
Shortening	75.1	3 lb. can all vegetable, Crisco brand
Soft drink	75.1	1 qt. Coca-Cola (75.1–79.2); 2 liter (79.3–92.4)
Steak	75.1	lb.; round steak (75.1–80.3); T-bone steak (80.4–92.4) USDA Choice
Sugar	79.2	5 lbs. cane or beet (79.2–92.3); 4 lbs. cane or beet. 92.4
Canned peas	75.1	#303 can 15–17 oz. (75.1–85.4); 17 oz. (86.1–92.4); Del Monte or Green Giant

APPENDIX: DESCRIPTIONS OF COMMODITIES INCLUDED

Item	Date added	Description
Tennis balls	82.2	Wilson or Penn brands, yellow, can of 3 heavy duty
Tissue	75.1	1 roll (75.1–79.1); 4 rolls (79.2–80.2); Kleenex brand 175 count box (80.3–92.4)
Canned tomatoes	75.1	#303 can 15–17 oz. (75.1–85.4); 14.5 oz. (86.1–92.4); Del Monte or Green Giant
Toothpaste	82.2	6 to 7 oz. tube Crest, or Colgate
Canned tuna	82.2	6.5 oz., Starkist or Chicken of the Sea, packed in oil (82.2–91.3); 6.125–6.5 oz (92.4)
Underwear	82.2	Package of 3 briefs, sizes 28/30–34/36 (82.2–90.3); sizes 10–14 (90.4–92.4)
Washing powder	75.1	49 oz. (75.1–88.4); 42 oz. (89.1–92.4); Giant Tide, Bold, or Cheer
Whole chicken	75.1	lb.; Grade A frying
Wine	82.2	Paul Masson Chablis 750 milliliter bottle (82.2–83.4), Paul Masson Chablis 1.5 liter (84.1–90.3) Gallo Sauvignon Blanc 1.5 liter (90.4–91.3); Gallo Chablis Blanc 1.5 liter (91.3–92.4)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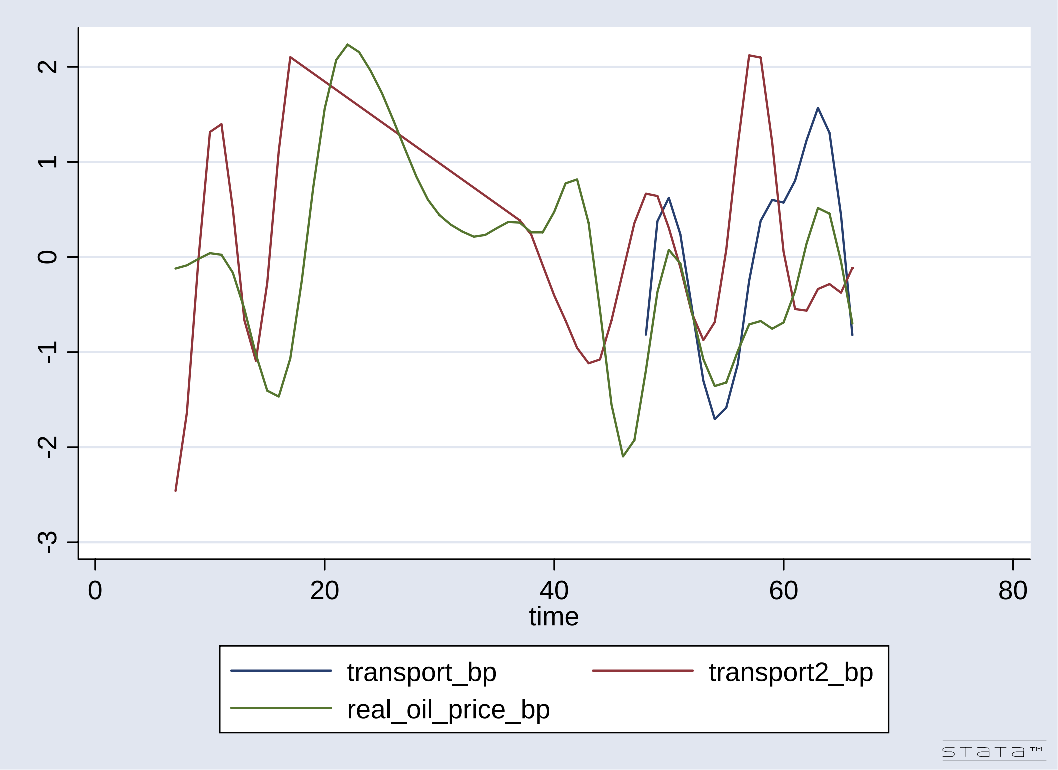

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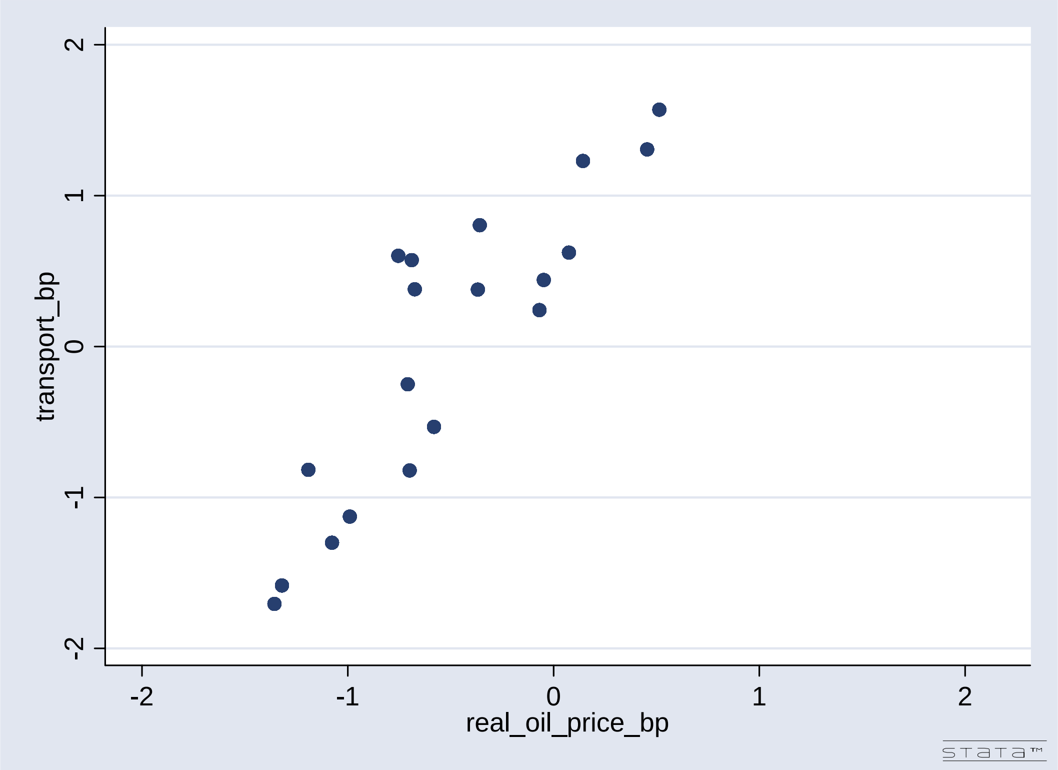

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Factor loadings from cross section

Good	Transport	Retail	XS R2	Relative transport
bacon	0.801	-0.298	0.099	1.000
Beauty salon	0.721	-0.103	0.032	1.000
beer	1.085	-0.546	0.063	1.000
bowling	0.896	-0.149	0.060	1.000
Canned Peaches	0.659	-0.037	0.030	1.000
canned tomatoes	1.030	-0.132	0.053	1.000
coffee	1.572	-0.402	0.077	1.000
corn flakes	0.764	-0.058	0.060	1.000
dentist	0.754	-0.007	0.042	1.000
dry cleaning	0.497	-0.084	0.036	1.000
fried chicken	1.063	-0.002	0.071	1.000
frozen corn	0.436	-0.192	0.030	1.000
Liquor	0.639	-0.029	0.045	1.000
Man's shirt	0.967	-0.218	0.053	1.000
McDonalds	1.418	-0.049	0.071	1.000
Shampoo	1.709	-0.136	0.109	1.000
shortening	0.412	-0.138	0.016	1.000
sugar	0.711	-0.018	0.047	1.000
tissue	0.496	-0.200	0.040	1.000
wine	0.526	-0.192	0.011	1.000
steak	1.659	0.074	0.212	0.957
lettuce	1.842	0.099	0.124	0.949
Canned Orange Juice	0.701	0.050	0.060	0.934
tennis balls	1.557	0.249	0.060	0.862
canned tuna	1.786	0.307	0.092	0.853
doctor	0.891	0.199	0.049	0.817
game	2.359	0.538	0.170	0.814
whole chicken	2.076	0.485	0.182	0.811
soft drink	1.622	0.396	0.111	0.804
washing powder	2.361	0.577	0.142	0.804
potatoes	1.075	0.271	0.112	0.799
Auto maintenance	1.464	0.411	0.169	0.781
bananas	0.696	0.259	0.118	0.728
underwear	1.029	0.383	0.063	0.728
Baby food	1.133	0.434	0.124	0.723
bread	0.437	0.187	0.110	0.700
canned peas	0.734	0.350	0.058	0.677
toothpaste	0.483	0.255	0.057	0.655
hospital room	1.859	0.996	0.283	0.651
cheese	0.326	0.212	0.027	0.606
eggs	0.487	0.330	0.144	0.596
man's haircut	1.123	1.007	0.167	0.527
asprin	0.809	0.874	0.098	0.481
Appliance repair	1.277	1.620	0.290	0.441
margarine	1.054	1.396	0.245	0.430
ground beef	1.064	1.435	0.270	0.426
movie	0.806	1.088	0.193	0.426
Jeans	0.997	2.072	0.342	0.325
Pizza	0.069	0.167	0.009	0.292
milk	0.081	1.693	0.219	0.045
cigarettes	-0.853	1.087	0.106	0.000
Average	**0.984**	**0.324**	**0.107**	

Factor loadings from time series

Good	Transport	Retail	TS R2	Relative transport
coffee	-0.888	-0.402	0.016	
Man's shirt	-0.182	-0.218	0.001	
sugar	-0.042	-0.018	0.004	
bacon	1.692	-0.298	0.136	1.000
Beauty salon	0.414	-0.103	0.010	1.000
beer	1.177	-0.546	0.053	1.000
bowling	0.392	-0.149	0.006	1.000
Canned Peaches	0.559	-0.037	0.011	1.000
canned tomatoes	0.829	-0.132	0.027	1.000
corn flakes	0.642	-0.058	0.040	1.000
dentist	0.204	-0.007	0.005	1.000
dry cleaning	0.326	-0.084	0.009	1.000
fried chicken	0.547	-0.002	0.009	1.000
frozen corn	0.590	-0.192	0.030	1.000
Liquor	0.090	-0.029	0.008	1.000
McDonalds	0.219	-0.049	0.002	1.000
Shampoo	0.955	-0.136	0.035	1.000
shortening	0.278	-0.138	0.011	1.000
tissue	0.086	-0.200	0.005	1.000
wine	0.333	-0.192	0.010	1.000
steak	1.165	0.074	0.038	0.940
lettuce	0.882	0.099	0.015	0.899
canned tuna	1.886	0.307	0.042	0.860
washing powder	2.638	0.577	0.105	0.820
whole chicken	1.603	0.485	0.054	0.768
tennis balls	0.656	0.249	0.006	0.725
Auto maintenance	1.000	0.411	0.051	0.709
canned peas	0.467	0.350	0.024	0.572
game	0.672	0.538	0.009	0.555
Baby food	0.435	0.434	0.008	0.501
bananas	0.240	0.259	0.005	0.481
eggs	0.303	0.330	0.040	0.479
movie	0.823	1.088	0.119	0.431
Jeans	1.055	2.072	0.082	0.337
underwear	0.137	0.383	0.001	0.264
cigarettes	0.373	1.087	0.041	0.256
potatoes	0.060	0.271	0.006	0.181
margarine	0.301	1.396	0.067	0.177
cheese	0.043	0.212	0.035	0.168
milk	0.276	1.693	0.010	0.140
Appliance repair	-0.691	1.620	0.028	0.000
asprin	-1.452	0.874	0.036	0.000
bread	-0.025	0.187	0.006	0.000
Canned Orange Juice	-0.400	0.050	0.012	0.000
doctor	-0.286	0.199	0.039	0.000
ground beef	-0.110	1.435	0.002	0.000
hospital room	-0.042	0.996	0.029	0.000
man's haircut	-1.487	1.007	0.046	0.000
Pizza	-0.295	0.167	0.037	0.000
soft drink	-0.899	0.396	0.026	0.000
toothpaste	-0.451	0.255	0.087	0.000
Average	**0.335**	**0.324**	**0.030**	

	Beta(p1-p2,p2)^2			Correlation(p1,p2)			Var(p1-p2)/Var(p2)		
	1	2	3	4	5	6	7	8	9
Transport margin		– 0.6546 **	0.9191 *		0.9570 ***	– 0.8695 *		– 1.1561	0.3299
		(0.3014)	(0.5361)		(0.2664)	(0.4721)		(0.8013)	(1.4317)
Similarity			– 4.3827 ***			5.0868 ***			– 4.1385
			(1.2374)			(1.0898)			(3.3045)
Distance (log)	0.028363 ***			– 0.0240 ***			0.1063 ***		
	0.007811			(0.0065)			(0.0210)		
Observations	1,159	1,216	1,216	1,159	1,216	1,216	1,159	1,216	1,216
R2	0.010	0.003	0.012	0.011	0.003	0.026	0.021	0.001	0.001