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Konstantin Gluschenko

Russia's common market takes shape

Price convergence and market integration among Russian regions

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Konstantin Gluschenko

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Abstract

This paper analyzes the spatial structure of goods market integration in Russia, characterizing regions into three states: (a) integrated, (b) not integrated but trending toward integration, and (c) not integrated and not trending toward integration. Using time series of the cost of a staples basket across 75 regions of Russia for 1994-2000, I exploit a nonlinear cointegration relationship with an asymptotically subsiding trend to capture movement toward integration. The analysis suggests that 36% of Russian regions were integrated with the national market over 1994-2000, 44% were in the process of integrating with the national market, and 20% of regions were not integrated and not trending toward integration.

JEL classification: C32, P22, R10, R15

Keywords: market integration; law of one price; price dispersion; convergence; Russian regions.

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Konstantin Gluschenko

Russia's common market takes shape: Price convergence and market integration among Russian regions

Tiivistelmä

Tässä työssä analysoidaan Venäjän hyödykemarkkinoiden maantieteellistä integraatiota. Alueet jaotellaan kolmeen: a) integroituneet, b) alueet, jotka eivät vielä integroituneet, mutta joiden integraation aste kasvaa, ja c) alueet, jotka eivät ole integroituneita ja joiden integraation aste ei kasva. Markkinoiden integraation astetta tutkitaan peruselintarvikkeista koostuvan hyödykekorin avulla 75:llä eri alueella. Empiirisessä analyysissä käytetään epälineaarista yhteisintegroituvuusmenetelmää, jossa trendimuuttuja on asymptoottisesti pienenevä, minkä tulkitaan merkitsevän integraation lisääntymistä. Analyysin mukaan 36 % Venäjän alueista oli integroitunut kansallisten markkinoiden kanssa, 44 % alueista ei ollut integroitunut, mutta integraation aste oli kasvussa, ja 20 % kuului ryhmään, joka ei ollut integroitunut ja integraatio ei lisääntynyt vuosina 1994–2000.

Asiasanat: markkinoiden integraatio, yhden hinnan laki, hintojen hajonta, konvergenssi, Venäjän alueet

1 Introduction

Political changes and Russia's rapid shift in the early 1990s from the centrally planned economy to one governed by market principles gave rise to a dramatic regional fragmentation of its economic space (Berkowitz and DeJong, 2003; Gluschenko, 2003). As a result, reunification of economic space has become major political talking point in Russia today. Some commentators even suggest that politicians' ability to deal with the problem has become a litmus test for judging the country's overall success at market reform.

A single economic space is manifested chiefly as integration of the goods market. Gluschenko (2003, 2004a) proposes that after a period of increased disconnectedness of the Russian market, a trend toward market integration emerged in 1994. Berkowitz and DeJong (2001, 2003) obtain similar results. These papers all consider, however, the temporal pattern of market integration in Russia rather than the spatial pattern. Their results are obtained through cross-sectional analysis and averaged across country's regions.

This paper deals with the spatial structure of goods market integration in Russia through time series analysis. Spatial structure is examined by considering three possible states for each region: integrated, not integrated but trending toward integration, or not integrated and not trending toward integration.

To model movement toward integration (long-run inter-market price convergence), I introduce a class of intermediate processes between non-stationary and stationary processes, specifically non-stationary processes that become stationary over time. This is modeled by an autoregression with a nonlinear, asymptotically subsiding trend. Two markets are deemed to be trending toward mutual integration when their price differential satisfies this model. Otherwise, I test to see whether the markets are integrated, using a conventional AR(1) model. In both cases, a structural break characterizing the 1998 financial crisis in Russia is taken into account. The source data for the empirical analysis are time series of the cost of a staples basket across 75 regions of Russia for 1994-2000 with a monthly frequency, the average Russian cost used as a representative of the national market.

Using this methodology, I find 36% of Russian regions to be integrated with the national market, 44% of regions trending toward integration with the national market, and 20% non-integrated with no trend toward integration. Since regions both trending and not trending toward integration are found, the overall market direction is initially unclear. Examining the behavior of price dispersion, however, reveals convergence of standard deviations of regional prices (σ-convergence). Thus, despite the presence of regions not tending to integration, the predominant trend is toward increased market integration. Non-integrated regions exhibit no σ-divergence.

The issue of market integration in transition economies has been the subject of a number of studies. Using cointegration analysis, Gardner and Brooks (1994), Goodwin *et al.* (1999), and Berkowitz *et al.* (1998) examine price dispersion among Russian cities during the early transition years (through 1995). They find the Russian market weakly integrated with signs of potential improvement. Berkowitz and DeJong (1999) subsequently identify a "Red Belt" group of pro-Communist and anti-market-reform regions as a culprit behind segmentation of the Russian market. Berkowitz and DeJong (2001, 2003) estimate a segment of the integration trajectory for Russia (corroborated by Gluschenko, 2003, with an alternative methodology). Analyzing cointegration and threshold relationships for pairs of aggregated Russian regions, Gluschenko (2002) and Gluschenko and Koneva (2004) find integrated and non-integrated pairs.

Conway (1999), using 1993-1996 data, examines price convergence among market locations within Kiev, Ukraine. He finds significant evidence of price convergence due to arbitrage by buyers and sellers at the various local markets, but also sizeable and persistent divergences from the law of one price. Cushman *et al.* (2001) compare prices for foods in Kiev during 1991-1992 with the prices of similar goods in the US. Commodity real exchange rates are found to possess deterministic trends that should close the yawning initial price gap.

This paper contributes to the above literature in two aspects. From the methodological standpoint, it proposes a time series method of analyzing for trends toward integration, as failure to consider such trends may result in overstatement of the problems of markets in transition and fail to capture the essence of the transition process itself. From the empirical standpoint, the paper obtains a geographical pattern of market integration that covers nearly the entire territory of Russia. Taken jointly, the results of Gluschenko (2003) and this paper provide a two-dimensional, time-space pattern of Russia's market integration. The paper also ties in with the literature on empirics of economic growth.[1] For exam-

[1] Michael Beenstock has pointed out the resemblance of the convergence problem in economic growth and the problem of price dynamics.

ple, the proposed method for analyzing price convergence also may have potential in analysis of income convergence.

The remainder of the paper is organized as follows. In the next section, methodology of the analysis and the data used are described. In section 3, empirical results are presented. Conclusions are offered in section 4.

2 Methodology and data

2.1 Strategy of the analysis

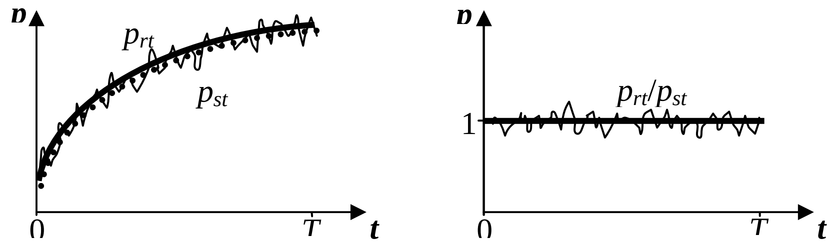
Perfect integration of a spatially distributed goods market implies an absence of impediments to the movement of goods between all spatial segments (e.g., national regions). In other words, a perfectly integrated market would operate like a single market despite spatial segmentation. The price of a (tradable) good across regions would be uniform so that the law of one price, maintained by inter-regional arbitrage, holds. Thus, the law of one price may be used as a theoretical benchmark for empirically analyzing goods market integration.

Market integration in Russia can be seen as a two-stage process, involving an initial stage of progressive segmentation beginning in January 1992 and a second stage of increased integration beginning around 1994. The second stage is the subject of this study. I hypothesize that the Russian goods market will eventually come to the final steady state of complete integration, i.e. a state of price equality across all regions. In this second stage of evolution, the market may be said to be in transition to this steady integration state. Hence, I suggest three types of regions can exist: (a) integrated regions, where price equality already prevails; (b) non-integrated regions trending toward integration, i.e. prices are converging toward a common level; and (c) non-integrated regions that show no indication of an integrating trend. For brevity, hereafter regions from the second group are referred to as "regions trending toward integration", and regions from the third group are referred to as simply "non-integrated regions."

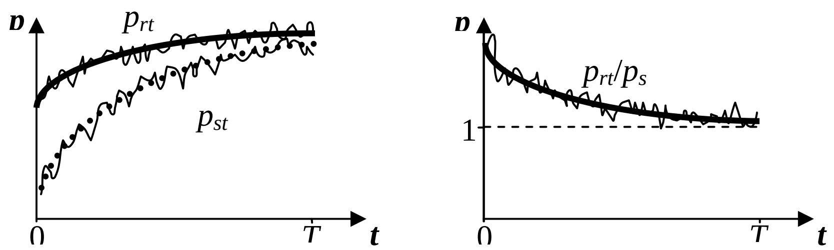
In the above context, the term *convergence of prices* becomes ambiguous. Indeed, when considering types (a) and (b), two distinct concepts of convergence are possible. Figure 1 illustrates the difference between the concepts: the thin lines depict actual dynamics of prices, while the thick lines represent their theoretical long-run trajectories. (Hereafter,

p_{rt} and p_{st} denote the price of a good in regions r and s, respectively, at time $t \in [0, T]$, and $p_{rst} = p_{rt}/p_{st}$. The logarithmic representation $P_{rt} = \ln(p_{rt})$, $P_{st} = \ln(p_{st})$, and $P_{rst} = \ln(p_{rt}/p_{st})$ will also be used below.)

Fig. 1. Two concepts of price convergence



(a) Short-run convergence (ordinary cointegration)



(b) Long-run convergence (catchngp)

These two concepts can be described as follows:

Figure 1(a) implies regions r and s are type (a). They are *in* spatial equilibrium, such that price disparities between regions are merely random shocks dying out over time. Prices fluctuate around parity and permanently tend to return to it. This is the case dealt with in the literature on the law of one price and purchasing power parity (convergence to the law of one price/PPP). The term "convergence" here relates to the shocks, implying their convergence to zero. It characterizes the short-run behavior of prices. The long-run behavior of prices is described by the trajectory

$$p_{rt}/p_{st} = 1, \quad t = 0,\ldots,T. \tag{1}$$

Thus, I designate this concept as "short-run convergence."

Figure 1(b) implies that regions r and s are type (b). The regions are *trending toward* spatial equilibrium:

$$\lim_{t\to\infty} p_{rt} / p_{st} = 1. \quad (2)$$

We see prices in s catch up with prices in r in the figure. Indeed, price disparity permanently diminishes over time and prices fluctuate around this general trend due to random shocks. This is the case the literature on economic growth (regarding incomes, outputs, etc.) refers to simply as "convergence." Here, in the short run, the prices converge to the long-run trajectory (i.e. random deviations die out over time), and the trajectory itself converges to the parity line p_{rt}/p_{st} = 1 over the long run. Here, "convergence" relates to the prices themselves, implying long-run convergence of their differences to zero over time. Hence, I designate this concept "long-run convergence."

For both short-term and long-term convergence, absolute price parity is taken as the steady state. This implies perfect integration – a rare condition in the real world. We would reasonably expect persistent (equilibrium) difference in prices between r and s induced by natural market frictions such as physical distance and difficult access to a number of regions. Thus, it may be more realistic to relax the criterion for market integration, allowing for such market frictions. In such case, relative price parity would have to be dealt with. Unity on the right side of (1) and (2) can be substituted for an arbitrary constant ratio of prices, α_{rs}.[2]

The trouble here is that α reflects both the effect of natural, irremovable market frictions (which is compatible with the notion of integration) and the effect of artificial, transient ones that impede market integration. This can be formalized as $\alpha = \alpha_e(L_{rs})\cdot\alpha_f$, where α_e is the effect of transportation costs proxied by distance between r and s, L_{rs}, and α_f is the effect of "anti-integration forces." In the context of a pairwise time series analysis, however, there is no way to distinguish α_e and α_f. This is why the strict version of the law of one price is adopted in the paper as a benchmark for integration, any deterministic difference in prices being interpreted as an indication of non-integration. Certainly, this may result in understatement of the degree of market integration. Therefore, at the end of Section 3 I check to see whether non-integration is predominantly due to persistent interregional differences in prices or to stochastic or deterministic divergence of prices.

Testing for the equality of prices or price levels, i.e. for relationship (1), is a conventional exercise in papers on the law of one price and PPP. The test is whether (log) re-

[2] Exploiting cross-section analysis, Gluschenko (2003, 2004a) has implemented such a relaxation.

gional prices P_{rt} and P_{st} are cointegrated with the predetermined cointegrating vector (1, –1), or, equivalently, whether price differential P_{rst} is stationary. However, in providing an "all-or-nothing" answer, this traditional approach is impotent in revealing a transitional case described by (2), i.e. the case where a process $\{P_{rst}\}_{t=0,\dots,T}$ is not stationary, but tends to stationarity over time. Using conventional cointegration analysis, such a process would be simply recognized as non-stationary, giving no way to separate region groups (b) and (c).

There are several approaches to this problem. The issue of long-run convergence is extensively addressed in the economic growth literature (see e.g. the survey by Durlauf and Quah, 1999).

The most widely used concepts of convergence in the economic growth context are σ-convergence and β-convergence (Barro and Sala-i-Martin, 1992). Reformulated in the terms of prices, σ-convergence occurs when the cross-sectional dispersion of prices, measured, e.g. by the standard deviation, $\sigma(P_t)$, tends to decrease over time: $\sigma(P_t)/\sigma(P_{t-\tau}) < 1$. In the same terms, if the regression of P_{rt} on $P_{r,t-\tau}$ yields $\beta < 1$, where β is the coefficient on $P_{r,t-\tau}$, then it is said that the data set exhibits β-convergence. Testing cross-sectionally, both approaches yield a spatially aggregated result, not a spatial pattern of convergence. They are thus unsuitable for solving our proposed problem.

A few researchers exploit a time series concept referred to as "forecast convergence" by Bernard and Durlauf (1995) and "stochastic convergence" by Carlino and Mills (1996). Bernard and Durlauf's paper defines convergence essentially as in (2), but tests for convergence with (1), applying standard cointegration analysis. Which is to say the authors do not deal with long-run convergence as such, examining only whether convergence has been completed by the beginning of a given time period (i.e. short-run convergence). Carlino and Mills (1996) employ a cointegration relationship with a deterministic linear trend. Provided that the trend of an inter-location difference is directed towards zero, stationarity around this trend is supposed to be evidence of convergence. (Cushman *et al*. (2001) apply a similar way to analyze price convergence.) However, since this test is not compatible with (2), such evidence is rather unreliable: having reached the zero value, the difference would be driven further by the linear trend and increase again (in absolute value) with the opposite sign.

Indeed, to analyze convergence in progress, a time series model should include a negative trend. However, in order to satisfy (2), this trend has to subside asymptotically, which results in a nonlinear cointegration relationship. We adopt this approach. Convergence of prices to the equality is modeled as

$$p_{rt}/p_{st} = 1 + \gamma e^{\delta t},\ \delta<0. \quad (3)$$

To economize notation, the region indices for parameters (and the disturbances discussed below) are suppressed.

Parameter δ defines convergence speed. The sign of γ shows the direction of convergence. If $\gamma < 0$, the price in *r* increases faster than in *s* and catches up with the latter. If $\gamma > 0$, the price in *r* rises slower than in *s*. γ is the initial (at $t = 0$) deviation of prices from parity. If $\gamma = 0$, (3) degenerates to (1), whereby convergence of prices is said to be complete by the start of the time period under consideration. Hence, the law of one price holds for regions *r* and *s*.

2.2 Econometrics

To derive a testable version of relationship (3), the logarithmic representation of prices is used and stochastic disturbances, ν_t, are taken into account. They are presumed to be a first-order autoregressive process:

$$P_{rst} = \ln(1 + \gamma e^{\delta t}) + \nu_t, \quad \nu_t = (\lambda + 1)\nu_{t-1} + \varepsilon_t, \quad (4)$$

where ε_t is white noise, and γ, δ, and λ are parameters to be estimated. Hereafter, $t = 1,\dots,T$. Substituting the second equation in (4) into the first gives a nonlinear model to be estimated and tested:

$$\Delta P_{rst} = \lambda P_{rs,t-1} + \ln(1 + \gamma e^{\delta t}) - (\lambda + 1)\ln(1 + \gamma e^{\delta(t-1)}) + \varepsilon_t. \quad (5)$$

I test whether time series $\{P_{rst}\}$ has no unit root, i.e. that the process is stationary around the trend, and if so, whether the time series has a subsiding trend, i.e. $\gamma \neq 0$ and $\delta < 0$. In other words, I test the hypotheses H_1: $\lambda = 0$ (against $\lambda < 0$), H_2: $\gamma = 0$ (against $\gamma \neq 0$), and H_3: $\delta \geq 0$ (against $\delta < 0$). Throughout the paper, the 10% significance level is adopted.

To test the unit root hypothesis, H_1, the *t*-ratio of λ is used as the test statistic, denoted as τ_{NL}. The distribution of this statistic differs from the Dickey-Fuller distributions and has not been documented in the literature. Therefore, to derive *p*-values, the empirical distribution of τ_{NL} under the null hypothesis has been estimated implementing a large set of simulations (see Appendix for details and simulation results). To eliminate serial correlation from residuals, the Phillips (1987) transformation is applied to $\hat{\tau}_{NL}$ using the Newey-West (1994) automatic bandwidth selection method with a Bartlett spectral kernel.[3]

If the unit root in (5) is rejected, hypotheses H_2 and H_3 are tested. Since the time series is stationary, the ordinary *t*-test is valid for this. If either of H_2 and H_3 is not rejected, there is no deterministic trend of the given form in the time series (or, when $\delta > 0$, the trend is not subsiding). In such an event, as well as in the case of non-rejection of unit root, I test whether the process is governed by law (1), as described below.

The joint rejection of H_1, H_2, and H_3 is interpreted as evidence that the time series tested fluctuates around an asymptotically subsiding trend. Hence, prices in *r* and *s* are converging to equality, so these regions are classed with those trending towards integration. Parameter λ is interpreted as the rate deviations from trajectory (3) caused by random shocks die out. (Alternatively, $t_{HL} = \ln(0.5)/\ln(1 + \lambda)$ defines the half-life of deviations. With a unit root, i.e. $\lambda = 0$, $t_{HL} = \infty$. Thus, the effect of random shocks is permanent; there is no return to trajectory (3). With no autocorrelation, i.e. $\lambda = -1$, $t_{HL} = 0$, the return to trajectory (3) is instantaneous.)

As above, we obtain a testable version of (1):

$$P_{rst} = \nu_t, \quad \nu_t = (\lambda + 1)\nu_{t-1} + \varepsilon_t, \tag{6}$$

or

$$\Delta P_{rst} = \lambda P_{rs,t-1} + \varepsilon_t, \tag{7}$$

which is the conventional AR(1) model.

[3] This procedure makes it possible to avoid loss of degrees of freedom caused by adding additional lags to the regression itself.

The hypothesis tested here is whether the time series has a unit root, H'_1: $\lambda = 0$ (against $\lambda < 0$); the Phillips-Perron test is used for this. The rejection of the unit root is interpreted as evidence that the time series fluctuates around zero, i.e. around the equality of prices in *r* and *s*. Therefore, such regions are classed as integrated. If H'_1 is not rejected, the regions are deemed non-integrated.

Note again the different roles of parameters γ and δ vs. parameter λ. The first two characterize the *long-run* behavior of the price differential trajectory, while λ characterizes the *short-run* properties of adjustment toward this trajectory.[4]

A peculiarity of price dynamics in Russia is that a number of regional price time series contain a structural break caused by the August 1998 financial crisis. The break point is not uniform across regions, varying from 1998:08 through 1999:02. With such a break, a time series might appear to have a spurious deterministic trend that biases inference toward non-rejection of a trend in (5) and toward non-rejection of a unit root in (7). To avoid this, (5) and (7) are augmented for breaks, taking the forms

$$\Delta P_{rst} = \lambda P_{rs,t-1} + \ln(1 + (\gamma + \gamma_B B_{\theta t})e^{\delta t}) - (\lambda + 1)\ln(1 + (\gamma + \gamma_B B_{\theta,t-1})e^{\delta(t-1)}) + \varepsilon_t, \qquad (5^*)$$

and

$$\Delta P_{rst} = \lambda P_{rs,t-1} + \gamma_B(B_{\theta t} - (\lambda + 1)\, B_{\theta,t-1}) + \varepsilon_t, \qquad (7^*)$$

where $B_{\theta t}$ is the structural change dummy such that $B_{\theta t} = 1$ if $t < \theta$, and zero otherwise.[5] The break point is found by estimating (5^*) and (7^*) for θ = 1998:08,…,1999:02, and then choosing θ that yields the least sum of squared residuals.

In (5^*), the sign of $\gamma + \gamma_B$ shows the direction of convergence before the break point. The sign of γ shows the convergence direction from the break point. When γ equals zero, it implies that prices in *r* and *s* have become close to the equality from the date of the break

[4] In the degenerate case of AR(1), the trajectory is a straight line along the time axis that represents price parity.

[5] Specification (7^*) is derived from (6), in which the first equation is augmented with the break dummy. This differs from the classical Perron (1990) specification. The common use of two dummies to characterize the break – level dummy and pulse – is superfluous. The latter, equaling 1 if $t = \theta$, and 0 otherwise, can be represented as $B_{\theta t} - B_{\theta,t-1}$. The Perron-type equation is a linear approximation of (7^*), allowing the coefficients on $B_{\theta t}$ and $B_{\theta,t-1}$ to be independent. This leads to parameter estimates that, while consistent, are not asymptotically efficient. For this reason the use of more adequate nonlinear equation (7^*) provides a more powerful test. See Gluschenko (2005) for details.

point onward. If the signs of γ and γ_B are the same, the break causes a price jump toward parity; and opposite signs imply the jump away from parity, provided that $|\gamma| > |\gamma_B|$.[6] The break dummy $B_{\theta t}$ is constructed so that the break is always directed toward parity to test whether *r* and *s* became integrated after the date of structural change. Given $\gamma_B > 0$, the crisis caused price-cutting in *r*. It otherwise increased the relative price in the region. The hypotheses tested for (5*) are the same as for (5), but H$_2$ which is substituted for H^*_2: $\gamma_B = 0$ (against $\gamma_B \neq 0$). For (7*), a similar hypothesis denoted $H^{*\prime}_2$ is tested in addition to H'_1. Hypotheses H_1 and H'_1 are tested through the same procedure as described for H_1 in (5); however, estimated empirical distributions of the unit root test statistic are used for time series with break, $\tau_{NL}(\theta)$ and $\tau_0(\theta)$, respectively (see Appendix).

Each time series $\{P_{rt}\}$ is analyzed as follows:

Step 1. Model (5*) is estimated and tested. If hypotheses H_1, H^*_2, H_3 and are jointly rejected, regions *r* and *s* are deemed to be trending toward integration, $\{P_{rst}\}$ containing a structural break. Otherwise, if the structural break is rejected, the analysis comes to Step 2. If it is not (and H_1 and/or H_3 is not rejected), the analysis continues at Step 3.

Step 2. Model (5) is estimated and tested. If hypotheses H_1, H_2, and H_3 are jointly rejected, *r* and *s* are deemed as trending toward integration. Otherwise, the analysis moves on to Step 3.

Step 3. Model (7*) is estimated and tested. If there is no structural break (hypothesis $H^{*\prime}_2$ is not rejected), the analysis moves to Step 4. If the unit root is rejected, *r* and *s* are deemed to be integrated (from the period of the break). If not, they are deemed as non-integrated, $\{P_{rst}\}$ containing a structural break.

Step 4. Model (7) is estimated and tested. If the unit root is rejected, *r* and *s* are deemed to be integrated and non-integrated otherwise.

There are 75 series of regional prices for Russia, yielding 2,775 region pairs. A standard way of reducing such a mass of pairwise comparisons in the literature on the law of one price and PPP is to take some location as a benchmark as in Parsley and Wei (1996) or Gardner and Brooks (1994), to name a few. Here, I choose the national market as a whole as the benchmark, because, in the intra-national context, such a benchmark is believed to be natural and far more reasonable than an arbitrary region. Thus, integration of each region with the

[6] The opposite inequality produces an exotic case of "overshooting." The jump crosses the price parity line, reversing the direction of convergence after the break point. Aside from insignificant γs, there are no such cases among the estimates obtained.

entire national market is analyzed, using only region-Russia pairs. That is, index s in the above relationships is fixed, and is set to $s = 0$, p_{0t} denoting the price in Russia as a whole. Thus, s is omitted hereafter; P_{rt} denotes percentage difference in prices between region r and Russia as a whole: $P_{rt} \equiv \ln(p_{rt}/p_{0t})$.

Finally, I make a caveat. There may be integration or long-run price convergence between two or more regions without integration with, or convergence to, the national market. This situation would imply "price convergence clubs" among regional markets, an analog of convergence clubs in economic growth (see e.g. Barro and Sala-i-Martin, 1992). This issue remains open when comparisons are made with a benchmark rather than within each region pair. Gluschenko (2004b, 2004c) provides additional analyses to clarify this matter.

When there are regions trending toward integration and non-integrated regions, the trend of the entire market is *a priori* unclear. In this case, the behavior of the entire cross-section over time can shed light on the issue. It is reasonable to believe that where σ-convergence is exhibited, the market as a whole is moving towards integration. The occurrence of σ-convergence where non-integrated regions have been detected is evidence that long-run convergence of prices prevails over divergence induced by those regions. To verify the separation of regions into three groups obtained through the time series analysis, σ-convergence is also analyzed for each group. The group of regions trending toward integration is expected to display σ-convergence. The group of integrated regions is expected to have a near-constant σ. The group of non-integrated regions should show σ-divergence if non-integration is due to random walking or deterministic price divergence. However, if the reason for non-integration is a persistent difference in prices, a near-constant σ would be expected.

2.3 Data

The price representative for the analysis is the cost of the basket of 25 food goods defined as the standard by the Russian statistical agency, Goskomstat, between January 1997 and June 2000. This basket covers about a third of foodstuffs included in the Russian CPI, but unlike the CPI, it has constant weights across regions and time.[7] The costs of the basket

[7] See Goskomstat (1996) for a description of basket composition.

(including those for the second half of 2000 and retrospectively calculated for 1994-1996) were obtained directly from Goskomstat.

The price data were collected in capital cities of the Russian regions. The sample covers 75 of Russia's 89 regions. Data are lacking for ten autonomous *okrugs,* the Chechen Republic, and the Republic of Ingushetia. Two other regions are omitted. The City of Moscow is simultaneously an administratively distinct "city-region" of the Russian Federation and the capital city of the surrounding Moscow Oblast. The same holds for St. Petersburg and the Leningrad Oblast. That is why these cities-regions are present in the sample, while their surrounding *oblasts* are not. The data are monthly, spanning 84 months, from January 1994 to December 2000.

There are missing observations in the time series used. Most occur in 1994, which has 42 missing observations (4.7% of the yearly total) in 17 regional time series. The remainder of the data set lacks only 9 observations. To fill the gaps, missing prices are approximated by the food component of the regional monthly CPIs. The interpolated value of p_{rt} is the arithmetic mean of the nearest known preceding price inflated to the required time point, t, and the nearest known succeeding price deflated to t.

One final aspect of the data used should be mentioned. Retail prices embody region-specific distribution costs that may violate the law of one price even if wholesale prices obey it. Gluschenko (2003) suggests two ways of dealing with the problem. The first is to produce proxies of wholesale prices from retail prices. Since prices are monthly, however, this is inappropriate as data on distribution costs and retail-wholesale margins are available only on a yearly basis. Thus, I interpret the spatial variation of distribution costs as an additional indication of poor integration. This means extending the notion of market integration and considering integration of the goods market as such in conjunction with integration of the related markets for distribution services and labor in retail trade.[8] In any case, results reported by Gluschenko (2003) suggest that patterns for retail and proxied wholesale prices do not significantly deviate from each other.

[8] Such a component of distribution costs like rent does not fit in with this. However, rent does not play a substantial role in costs of the Russian trade, account for only about 1% of retail prices of goods.

3 Empirical results

Table 1 summarizes results on integration of each individual region with the entire national market. For a given region, the table reports results for one of models (5^*), (5), (7^*), and (7), depending on which is accepted as describing price behavior in the region.[9] Reporting all parameters – λ, γ, γ_B, and δ – means the acceptance of model (5^*); reporting λ, γ, and δ implies that (5) is accepted. In either case, the region is deemed as trending toward integration. If there are only λ and γ_B in the table, then model (7^*) is accepted; and the only parameter λ is reported when (7) is accepted. In the last two cases, the region is deemed as integrated if the unit root is rejected (the *p*-value of the unit root test is less than, or equal to, 0.1); otherwise the region is deemed as non-integrated.

Standard deviations are presented in Table 1 in parentheses. Asterisks, ***, **, and *, denote significance at 1%, 5%, and 10% levels, respectively. Bold italics indicate *p*-values of the unit root test over 10%. Horizontal borders separate economic areas (*ekonomicheskiy rayon*). The composition of these areas and their names appear on the map in Figure 2. Regions are arranged geographically in the table according to their traditional ordering in Goskomstat's publications up to June 2000 (except the Kaliningrad Oblast, which is added to the Northwestern Area).

Table 1. Summary of estimations and unit root tests

Region	Unit root test *p*-value	λ	γ	Structural break (γ_B)	δ
1. Rep. of Karelia	0.003	-0.423 (0.091)	0.186 (0.030)***		-0.011 (0.004)***
2. Rep. of Komi[d]	0.002	-0.439 (0.092)	0.005 (0.058)	0.227 (0.072)***	-0.017 (0.006)***
3. Arkhangelsk Obl.[d]	0.006	-0.428 (0.093)	0.195 (0.049)***	0.119 (0.039)***	-0.014 (0.003)***
4. Vologda Obl.	0.001	-0.347 (0.089)		-0.043 (0.010)***	
5. Murmansk Obl.	***0.160***	-0.013 (0.009)		-0.207 (0.036)***	
6. St. Petersburg	***0.306***	-0.028 (0.024)		-0.183 (0.036)***	
7. Novgorod Obl.	0.000	-0.677 (0.106)		-0.034 (0.007)***	
8. Pskov Obl.	0.023	-0.181 (0.069)		-0.088 (0.021)***	
9. Kaliningrad Obl.	0.015	-0.173 (0.063)		-0.125 (0.030)***	
10. Bryansk Obl.[a]	0.066	-0.274 (0.083)	-0.385 (0.108)***	0.147 (0.088)*	-0.018 (0.004)***
11. Vladimir Obl.	0.025	-0.175 (0.067)		-0.122 (0.018)***	
12. Ivanovo Obl.	0.002	-0.301 (0.084)		-0.090 (0.012)***	
13. Kaluga Obl.	0.035	-0.239 (0.073)	-0.236 (0.075)***		-0.042 (0.017)**
14. Kostroma Obl.	***0.308***	-0.078 (0.053)		-0.090 (0.028)***	
15. Moscow[a]	***0.691***	-0.003 (0.013)		-0.070 (0.028)**	
16. Oryol Obl.	0.015	-0.328 (0.085)	-0.313 (0.029)***		-0.017 (0.003)***
17. Ryazan Obl.	0.017	-0.153 (0.060)		-0.083 (0.019)***	
18. Smolensk Obl.	0.000	-0.534 (0.101)	-0.090 (0.036)**	-0.133 (0.032)***	-0.009 (0.004)**
19. Tver Obl.	0.000	-0.344 (0.082)		-0.118 (0.013)***	
20. Tula Obl.	0.009	-0.299 (0.072)	-0.145 (0.053)***	-0.082 (0.044)*	-0.016 (0.005)***
21. Yaroslavl Obl.	0.000	-0.388 (0.088)		-0.077 (0.009)***	
22. Rep. of Mariy El	***0.330***	-0.014 (0.015)			

[9] The working paper version, Gluschenko (2004b), Appendix B, provides the full set of estimates.

Region	Unit root test *p*-value	λ	γ	Structural break (γ_B)	δ
23. Rep. of Mordovia	***0.196***	-0.015 (0.014)		0.125 (0.039)***	
24. Chuvash Rep.[b]	***0.544***	-0.012 (0.018)		-0.070 (0.027)**	
25. Kirov Obl.	***0.277***	-0.050 (0.040)		-0.125 (0.030)***	
26. Nizhni Novgorod Obl.[c]	0.063	-0.129 (0.057)		-0.099 (0.024)***	
27. Belgorod Obl.	0.000	-0.470 (0.095)	-0.261 (0.027)***		-0.012 (0.003)***
28. Voronezh Obl.[a]	0.000	-0.524 (0.098)	-0.646 (0.142)***	0.249 (0.129)*	-0.029 (0.003)***
29. Kursk Obl.	0.000	-0.471 (0.097)	-0.245 (0.025)***		-0.015 (0.003)***
30. Lipetsk Obl.	0.002	-0.468 (0.095)	-0.391 (0.071)***	0.134 (0.059)**	-0.015 (0.003)***
31. Tambov Obl.[b]	0.004	-0.362 (0.082)	-0.176 (0.046)***	-0.068 (0.033)**	-0.007 (0.003)**
32. Rep. of Kalmykia[b]	0.000	-0.548 (0.103)	-0.045 (0.038)	-0.117 (0.037)***	-0.012 (0.005)**
33. Rep. of Tatarstan	0.000	-0.614 (0.101)	-0.363 (0.058)***	0.077 (0.045)*	-0.008 (0.002)***
34. Astrakhan Obl.	0.000	-0.701 (0.106)	-0.181 (0.020)***		-0.025 (0.005)***
35. Volgograd Obl.[d]	0.000	-0.354 (0.084)		-0.099 (0.015)***	
36. Penza Obl.	0.026	-0.279 (0.078)	-0.227 (0.027)***		-0.010 (0.003)**
37. Samara Obl.	0.000	-0.376 (0.087)			
38. Saratov Obl.	0.014	-0.316 (0.082)	-0.178 (0.035)***		-0.010 (0.005)**
39. Ulyanovsk Obl.	0.000	-0.577 (0.098)	-0.600 (0.068)***	0.152 (0.057)***	-0.013 (0.002)***
40. Rep. of Adygeya	0.000	-0.772 (0.108)	-0.366 (0.068)***	0.118 (0.059)**	-0.018 (0.003)***
41. Rep. of Dagestan	0.000	-0.574 (0.101)	-0.122 (0.023)***		-0.012 (0.005)**
42. Kabardian-Balkar Rep.	0.000	-0.231 (0.040)	-0.828 (0.079)***		-0.093 (0.017)***
43. Karachaev-Cirkassian Rep.	***0.158***	-0.080 (0.044)			
44. Rep. of Northern Ossetia	0.002	-0.445 (0.093)	-0.243 (0.032)***		-0.025 (0.005)***
45. Krasnodar Krai	0.000	-0.619 (0.105)	-0.430 (0.157)***	0.234 (0.140)*	-0.020 (0.005)***
46. Stavropol Krai	0.000	-0.554 (0.100)	-0.165 (0.016)***		-0.009 (0.003)***
47. Rostov Obl.	0.000	-0.679 (0.106)	-0.185 (0.012)***		-0.007 (0.002)***
48. Rep. of Bashkortostan[d]	0.005	-0.240 (0.073)		-0.126 (0.024)***	
49. Udmurt Rep.[c]	0.015	-0.185 (0.064)		-0.129 (0.022)***	
50. Kurgan Obl.[c]	0.007	-0.131 (0.042)		-0.099 (0.031)***	
51. Orenburg Obl.[b]	0.017	-0.167 (0.060)		-0.110 (0.040)***	
52. Perm Obl.	0.003	-0.372 (0.082)	0.160 (0.074)**		-0.084 (0.039)**
53. Sverdlovsk Obl.	0.020	-0.292 (0.081)	0.119 (0.044)***		-0.021 (0.012)*
54. Chelyabinsk Obl.	0.000	-0.698 (0.105)			
55. Rep. of Altai	0.000	-0.401 (0.088)			
56. Altai Krai	***0.385***	-0.023 (0.024)		0.077 (0.039)*	
57. Kemerovo Obl.[e]	0.000	-0.310 (0.069)		0.038 (0.015)**	
58. Novosibirsk Obl.[e]	0.000	-0.306 (0.070)		0.033 (0.013)**	
59. Omsk Obl.[e]	0.000	-0.578 (0.101)	-0.910 (0.296)***	0.667 (0.282)**	-0.034 (0.005)***
60. Tomsk Obl.	0.000	-0.252 (0.071)			
61. Tyumen Obl.	0.027	-0.138 (0.056)		0.068 (0.024)***	
62. Rep. of Buryatia	0.004	-0.232 (0.073)		0.118 (0.022)***	
63. Rep. of Tuva	***0.233***	-0.073 (0.046)		0.118 (0.044)***	
64. Rep. of Khakasia[e]	0.015	-0.200 (0.068)		0.038 (0.018)**	
65. Krasnoyarsk Krai	0.012	-0.196 (0.066)		0.070 (0.026)***	
66. Irkutsk Obl.[f]	0.001	-0.342 (0.085)		0.147 (0.026)***	
67. Chita Obl.	0.001	-0.450 (0.091)	0.298 (0.076)***	0.106 (0.054)*	-0.012 (0.003)***
68. Rep. of Sakha (Yakutia)	***0.513***	-0.007 (0.013)			
69. Jewish Autonomous Obl.[f]	0.003	-0.422 (0.091)	0.183 (0.045)***	0.148 (0.035)***	-0.010 (0.003)***
70. Primorsky Krai	0.040	-0.282 (0.081)	0.545 (0.060)***		-0.008 (0.002)***
71. Khabarovsk Krai[d]	0.000	-0.571 (0.104)	0.298 (0.048)***	0.143 (0.034)***	-0.007 (0.002)***
72. Amur Obl.[c]	0.005	-0.216 (0.063)		0.170 (0.028)***	
73. Kamchatka Obl.[d]	***0.694***	-0.005 (0.014)		0.179 (0.063)***	
74. Magadan Obl.[d]	***0.359***	-0.008 (0.010)		0.155 (0.051)***	
75. Sakhalin Obl.[d]	***0.414***	-0.010 (0.014)		0.137 (0.055)**	

[a] Break in 1998:08; [b] Break in 1998:10; [c] Break in 1998:11; [d] Break in 1998:12; [e] Break in 1999:01; [f] Break in 1999:02. Breaks not marked take place in 1998:09.

Out of all 75 regions, 27, or 36%, are deemed as integrated with the national market. Another 15 (20%) are non-integrated regions that show no trend toward integration. The minimal *p*-value of the unit root test equals 0.158 among regions for which the unit root is not rejected in model (7) or (7^*). Thus, the test results can be taken as fairly reliable despite the low power of the unit root tests.

Taking the structural break into account significantly increases the number of integrated regions. The unit root for eight regions, rejected in (7^*), is not rejected in (7). As the break dummy equals 1 before the break point, and 0 thereafter, these regions became integrated in the "after-break" period. Hence, the 1998 financial crisis facilitated price equalizing among Russian regions, improving the pattern of regional integration. St. Petersburg provides the only opposite case, where the unit root is rejected in (7), but not in (7^*). The 1998 crisis caused a persistent rise in prices in that city compared to the average Russian price that prevented integration with the national market.

The structural break is not rejected for 23 of 27 integrated regions. Of these, 15 regions have an upward break, i.e. the crisis forced a rise in relative prices in these regions. All regions lie in the European part of Russia. For eight regions in the Asian part of Russia (Siberia and the Far East), the break is downward, implying a decline in relative prices. The same pattern is valid for non-integrated regions (the structural break is rejected for only three of them) with the sole exception of the Republic of Mordovia. Thus, the 1998 crises drew prices in the Asian and European parts of Russia together, since prices had, as a rule, been higher in the east than in the west prior to the crisis.

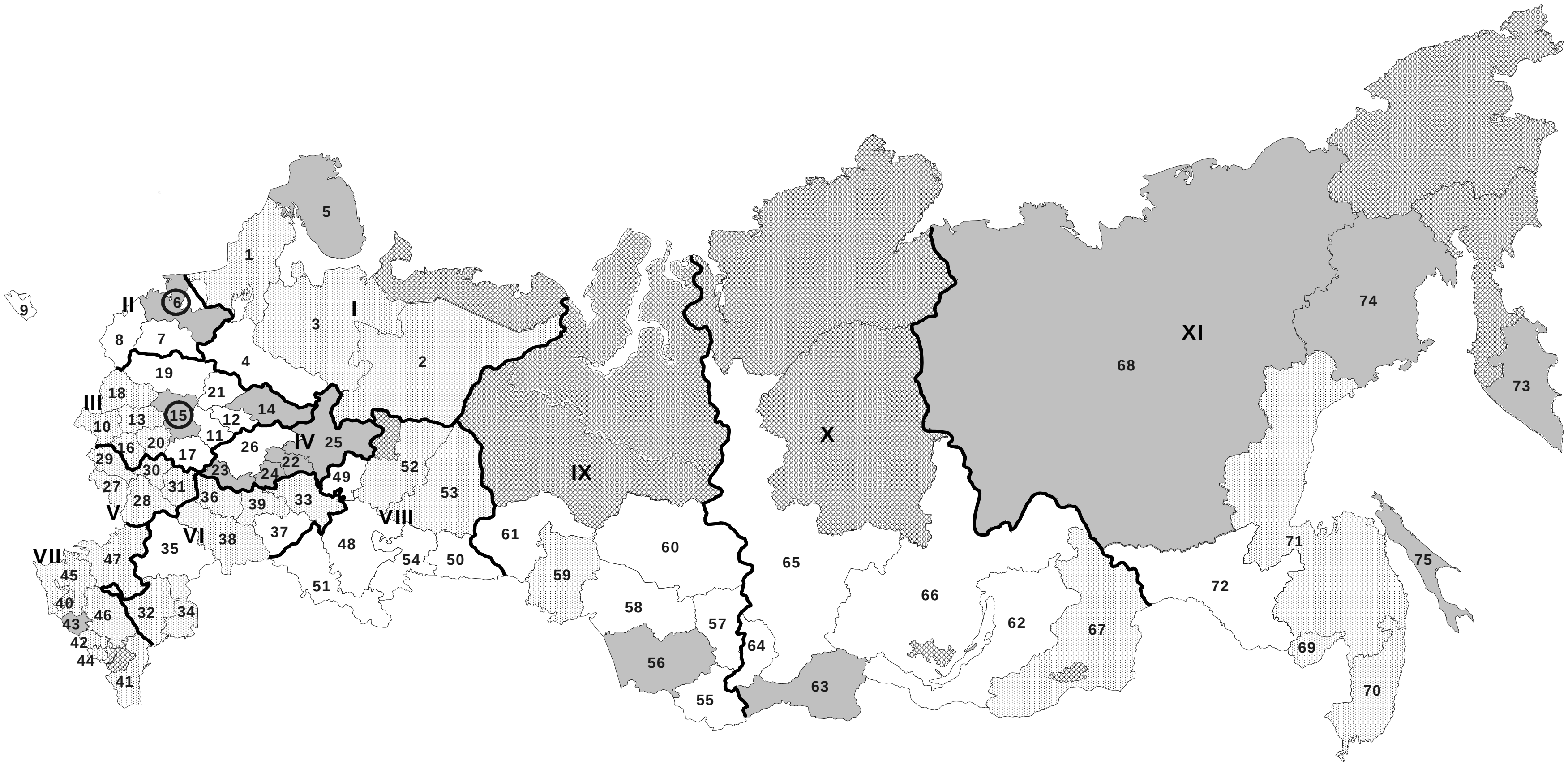
The number of regions tending to integration with the national market is 33, or 44% of the total. For most of them (24 of 33, or 73%), convergence is "upward", i.e. from lower prices towards the national average. Of these regions, the lowest starting price level, 0.17 ($=1 + \gamma + \gamma_B$), was found in the Kabardino-Balkar Republic; the highest one, 0.88, was in the Republic of Dagestan. There are nine regions (27% of 33 regions) with "downward" convergence. They have the starting price levels from 1.12 in the Sverdlovsk Oblast to 1.54 in the Primorsky Krai. All these are regions in the Northern area, Urals, Siberia, or the Far East. There is the only region with "upward" convergence, the Omsk Oblast in Western Siberia. Expressed as a percentage, $|e^{\delta} - 1|\cdot 100$, the convergence speed varies from 0.7% to 8.9% per month in the case of "upward" convergence, and from 0.7% to 8.1% in the case of "downward" convergence. The starting price gap, $|\gamma + \gamma_B|$, and the rate of "upward" convergence are strongly positively correlated: the correlation coefficient equals 0.79. However, the pattern is reverse for "downward" convergence: the greater the gap, the slower convergence. Here, the correlation coefficient equals –0.52.

The structural break is not rejected for about a half of regions (namely, 16) trending toward integration. In turn, these are divide almost in half between the nine in which the break has facilitated convergence (γ and γ_B have the same signs) and pushed prices toward the Russian average, and the eight regions where the break has pushed prices away from the average (γ and γ_B have opposite signs) and thus slowed convergence. There are two regions, the republics of Komi and Kalmykia, with statistically insignificant γ. The implication is that prices have come close to the national average after the break point. Thus, these regions might just as well be deemed integrated.

Neglecting the structural break would markedly distort the pattern. There are 12 cases, where the break is spuriously treated as a trend in (5). These regions would be deemed as trending toward integration, when they are, in fact, either already integrated or non-integrated without any trend toward integration.

There are 15 non-integrated regions (20% of 75 regions) that show no trend toward integration with the national market. If models (7) and (7^*) are augmented for the constant term, the unit root is not rejected only for two of these regions, the Magadan and Sakhalin *oblasts*. This suggests that non-integration is almost entirely caused by a *constant* non-zero disparity between prices in a given region and the national price, and not by deterministic or stochastic price divergence.

Overall, the 1998 crisis strongly affected regional price dynamics. Nevertheless, the behavior of prices remained intact in a number of regions. The break is rejected for 23 regions (31% of 75 regions). In these regions, the crisis caused a spike, after which relative prices returned to the previous trajectory.



Regions integrated with national market   Regions trending to integration   Non-integrated regions   Out of sample

For numerical designations of regions, see Table 1.

Thick lines are borders of economic areas, Roman numerals labeling the areas:

I. Northern area	IV. Volga-Vyatka area	VII. Northern-Caucasus area	X. Eastern Siberian area
II. North-Western area	V. Central Black Soil area	VIII. Urals area	XI. Far Eastern area
III. Central area	VI. Volga area	IX. Western Siberian area	

Fig. 2. Geographical pattern of market integration in Russia

The spatial structure of market integration is presented in Figure 2. About a half of the non-integrated regions are concentrated in Central Russia. In particular, all but one of the regions in the Volga-Vyatka area are non-integrated. The pattern is rather surprising, because these are small regions with relatively short distances between them. Moreover, this part of the country has highly developed transport infrastructure. It can be surmised that it is the atomistic administrative-territorial division of Central Russia that causes market segmentation: the more regional borders and governors, the more possibilities to impede inter-regional trade and diversify price policies across space. Curiously, the Ulyanovsk Oblast, which maintained price regulation and subsidies until the beginning of 2001, is trending toward integration with the national market. The Moscow time series has an "almost confident" unit root, $\lambda = -0.003$. No correlation, however, is found between non-integration and the "Red Belt" regions reported by Berkowitz and DeJong (1999) – even in the European part of Russia.

On the other hand, non-integrated regions are rare in Siberia and the Far East. This corroborates Gluschenko's (2003) finding that the Asian part of Russia, excluding difficult-to-access regions, is more integrated than European Russia. Figure 2 provides additional evidence that all difficult-to-access regions (the Murmansk, Magadan, Sakhalin, and Kamchatka *oblasts*, and the Republic of Yakutia) are, as might be expected, not integrated with the national market. It also supports Gluschenko's (2003, 2004a) insight that these regions markedly contribute to the overall disconnectedness of regional markets.

In the full set of estimates (Gluschenko, 2004b), the unit root in (7) or/and (7^*) is rejected for 20 regions recognized as trending toward integration. Thus, if the traditional approach to the time series analysis of integration is used, 47 regions (or 63% of the total) would be deemed as integrated with the national market, and 28 regions (37%) would be non-integrated.

Among all the 75 estimates of model (5), 13 non-subsiding trends ($\delta > 0$) occur, implying divergence of prices. However, ten of these trends have a statistically insignificant δ, and two have an insignificant factor γ. Moscow has the only significant non-subsiding trend. When the structural break is considered, the number of positive estimates of δ increases to 20 in model (5^*), seven of them for the same regions as in (5). Of these 20, 13 are insignificant, two are accompanied with non-rejection of the unit root in the model, and one is accompanied with insignificant $\gamma + \gamma_B$. In this case, the δ for Moscow is insignificant. Instead, there are four significant non-subsiding trends for other regions. For two of these, the unit root is rejected in (7^*), so only two cases of price divergence remain.

This pattern gives grounds to believe that the trend towards convergence of prices is predominant in the Russian market.

This view is supported by the dynamics of price dispersion plotted in Figure 3. The price dispersion is measured by σ_t, the standard deviation of prices normalized to the Russian average. The trajectory of σ_t suggests price dispersion over all regions was decreasing until mid-1999. This is clear evidence of σ-convergence in 1994-2000, suggesting that the Russian market is moving toward integration.

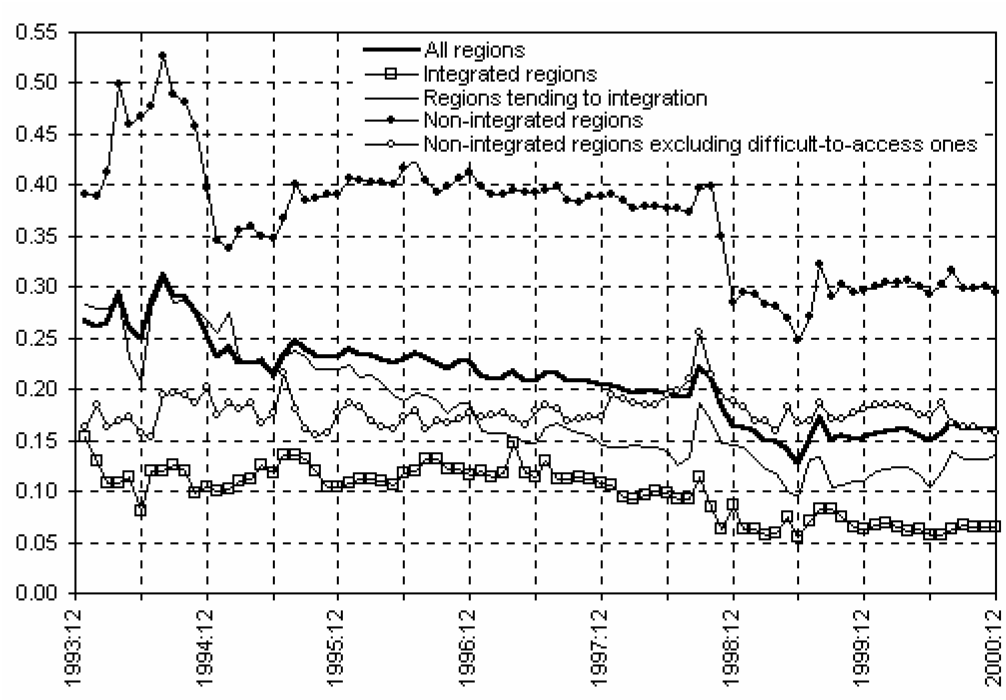


Figure 3. Standard deviations of log relative cost of the 25-item food basket

Additional trajectories for the region groups provide insight into the pattern of changes in price dispersion. For comparability, standard deviations for region groups are computed with the use of the mean over all regions rather than that over a given group. This implies that price dispersion is measured relative to the whole of the country, i.e. it is not within-group dispersion. Thus, price dispersion over all Russian regions is a weighted average of group dispersions, $\sigma_t = (R_1/R)\sigma_{t1} + (R_2/R)\sigma_{t2} + (R_3/R)\sigma_{t3}$, the weight being the proportion of the group in the total number of regions (σ_{ti} denotes the standard deviation of prices in region group i). The proportion of the integrated regions is 0.36, that of the non-integrated regions is 0.20, and that of the regions trending toward integration is 0.44.

The structural break caused by the August 1998 financial crisis is pronounced on the trajectories of σ and seems to reduce price dispersion. As expected, the main contribution to the decrease of price dispersion is from regions trending toward integration. While price dispersion in such regions and that in the whole of the country are roughly equal at the beginning of the time span under consideration, the gap between them widens quickly over time. For integrated regions, price dispersion is the lowest and near constant, fluctuating around a level of 0.11 before the 1998 crisis and 0.07 after January 1999.

The most price dispersion is inherent in the non-integrated regions. The trajectory for this group has the most pronounced structural break, reducing the group price dispersion by about a quarter. However, the main contribution comes from the difficult-to-access regions. Computing for non-integrated regions excluding those difficult to access, the trajectory of σ appears to have no break. Contrary to theoretical expectations, this subgroup does not exhibit increasing price dispersion. The reason is that there is almost no price divergence in the Russian market. Indeed, as mentioned above, the full set of estimates provides only two clear cases of price divergence; regions deemed as non-integrated are for the most part those having a persistent difference from the average Russian price.

4 Conclusions

Using the cost of the basket of 25 basic food goods as the price representative, the spatial structure of market integration in Russia in 1994-2000 was analyzed. It was found that over a third of Russian regions (36%) could be deemed as integrated with the national market over 1994-2000, while slightly less than half of regions (44%) could be classed as trending toward integration. One fifth of the regions (20%) were found non-integrated. However, final assessment may be overstated, since the strict version of the law of one price was used as an indication of integration. It does not allow for such an irremovable market friction as spatial separation of regions.

Overall, the results unambiguously suggest that the Russian market has been moving toward integration. The largest exception is the group of difficult-to-access regions. Logically, difficult access presents an insurmountable market friction, so the lack of integration of these regions is more likely due to geographical realities than a particular economic policy, national or regional.

The evolution of price dispersion plotted in Figure 3 suggests that this movement nearly ceased around the beginning of 2000. Extending the price dispersion trajectory to the end of 2004 in Gluschenko and Kulighina (2006) corroborates this. A reasonable explanation seems to be that price convergence in Russia was for the most part completed by that time, having reached a “feasible” bound of goods market integration. This raises the question of whether a Russian common market has emerged.

Reasoning from the *theoretical* benchmark of complete integration, the situation is fairly muddied, as much as a fifth of all regions are not integrated and not trending toward integration. However, when compared with an *actual* benchmark (say, the United States, which is widely held to have the most integrated goods market in the world), we arrive at a different conclusion.

Gluschenko and Kulighina (2006) perform such a comparison with the use of the costs of a 27-item grocery basket across US cities. Regarding Russia excluding difficult-to-access regions, they find price dispersion in the Russian market (represented by the staples baskets) comparable with that of the US market (represented by the grocery basket) by the early 2000s. Moreover, the estimated degrees of market integration in Russia and the United States in 2000 prove to be very close to each other. Thus, it can be concluded that Russia has a common market.

The issue of whether Russia has become a normal middle-income capitalist country as a result of the transition remains debatable, considering its economic and political system as a whole (see Shleifer and Treisman, 2005, vs. Rosefielde, 2005). But regarding goods market integration, we would agree with Shleifer and Treisman (2005) that Russia has become a fairly normal country.

Appendix

Unit root test statistics for models with nonlinear trend, with nonlinear trend and break, and with break only

To derive *p*-values of the *t*-ratio of λ that is used in the unit root test for model (5), the model was estimated over each of 500,000 simulated random walks to obtain an empirical distribution of this statistic under the null hypothesis. The statistic is referred to as τ_{NL}. Denoting the number of simulation *i*, the random walk series were generated as $P_t^{(i)} = P_{t-1}^{(i)} + \varepsilon_t^{(i)}$, where $\varepsilon_t^{(i)} \sim N(0,1)$; $t = 1,\ldots,83$; $P_0^{(i)} = 0$.

Table A1 reports some critical values of τ_{NL}. For comparison, MacKinnon's (1996) critical values for the Dickey-Fuller test with no constant, with constant, with constant and trend, and with constant, trend and trend squared (τ_0, τ_c, τ_{ct}, and τ_{ctt} statistic, respectively) for the sample size of 83 are reported as well. Figure A1 demonstrates the probability density of τ_{NL} and its cumulative distribution in comparison with those of conventional τ-statistics. Figure A2 plots the 10-percent tails of the cumulative distributions.

Table A1. Critical values of the unit root test τ-statistics

Significance level	τ_{NL}	τ_0	τ_c	τ_{ct}	τ_{ctt}
0.1%	-4.820	-3.363	-4.251	-4.808	-5.258
1%	-3.963	-2.593	-3.511	-4.072	-4.516
5%	-3.310	-1.945	-2.897	-3.465	-3.906
10%	-2.978	-1.614	-2.586	-3.159	-3.598
20%	-2.585	-1.228	-2.223	-2.804	-3.242

Fig. A1. Distributions of τ-statistics: (a) probability densities; (b) cumulative distributions

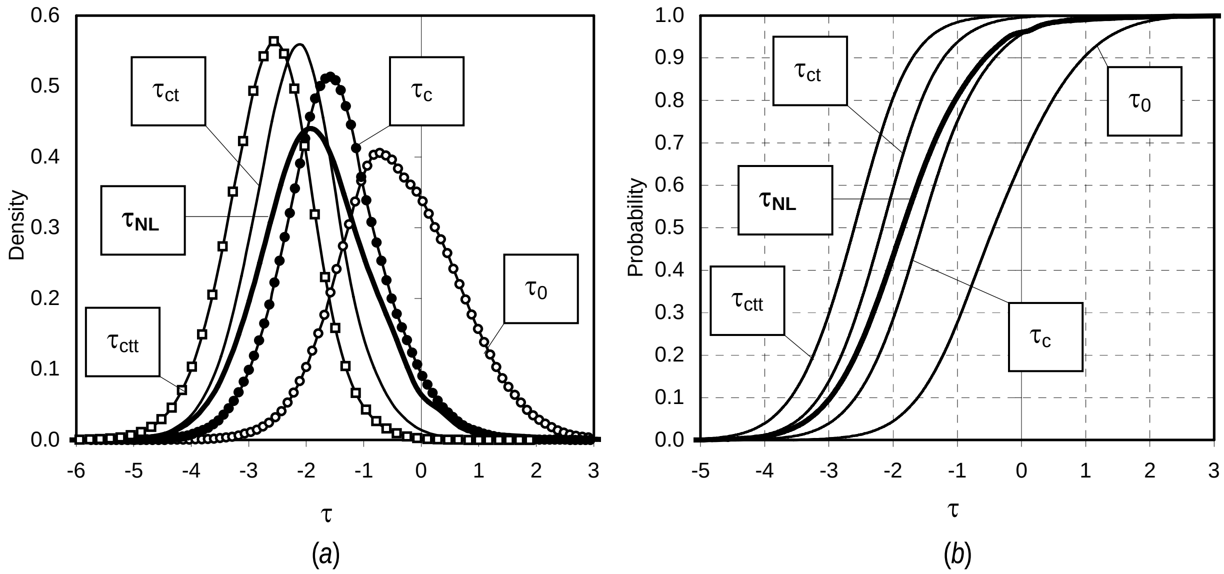
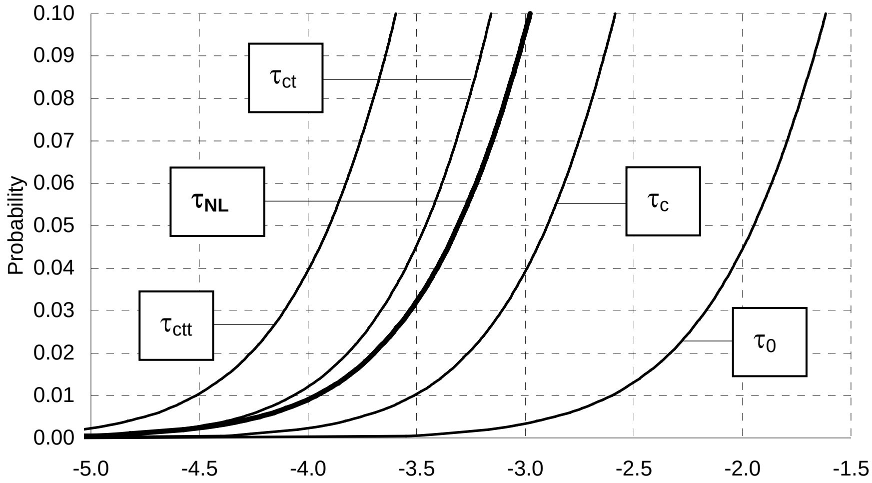


Fig. A2. Left-hand tails of cumulative distributions of τ-statistics



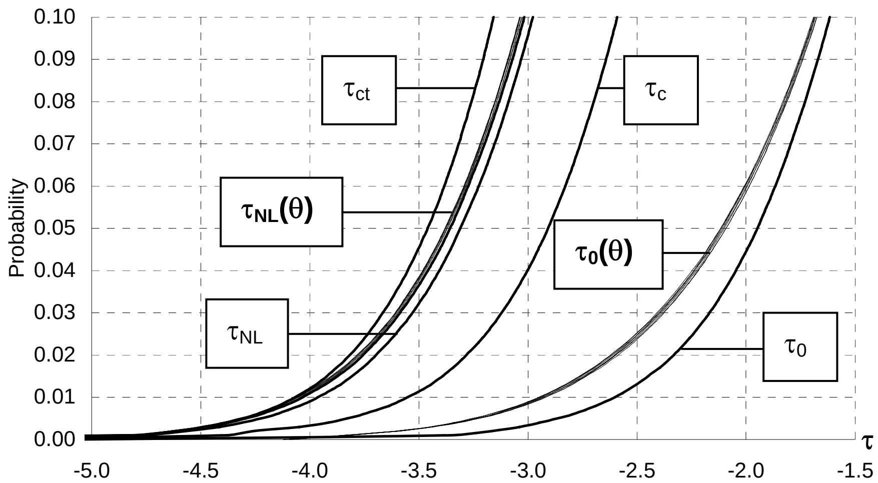
As seen from the table and figures, at any given test size (except those lower than 0.002), rejecting the unit root in the case of nonlinear trend of form (3) needs smaller (absolute) values for the statistic than in the case of linear trend (or quadratic trend, for that matter). Along most of its length, the cumulative distribution of τ_{NL} lies between τ_c and τ_{ct}.

Empirical distributions for the case of structural break in time series were computed in a similar way. The unit root test statistic for the model with a nonlinear trend and a structural break, i.e. model (5^*), is denoted by $\tau_{NL}(\theta)$, where θ is a break point. $\tau_0(\theta)$ labels the statistic for model (7^*), which includes a structural break only. Table A2 reports some critical values of these estimated statistics. Figure A3 demonstrates the 10-percent tails of their cumulative distributions. For comparison, selected Dickey-Fuller τ-statistics are included in Table A2 and plotted in Figure A3.

Table A2. Critical values of the unit root test τ-statistics for models with structural break

Model with nonlinear trend and break (5^*)									
Significance level	τ_{NL}	$\tau_{NL}(\theta)$ with θ =							τ_{ct}
		1998:08	1998:09	1998:10	1998:11	1998:12	1999:01	1999:02	
0.1%	-4.820	-4.853	-4.861	-4.875	-4.889	-4.882	-4.872	-4.872	-4.808
1%	-3.963	-4.034	-4.045	-4.052	-4.055	-4.064	-4.058	-4.065	-4.072
5%	-3.310	-3.357	-3.369	-3.372	-3.376	-3.379	-3.378	-3.381	-3.465
10%	-2.978	-3.017	-3.027	-3.030	-3.035	-3.036	-3.038	-3.039	-3.159
20%	-2.585	-2.622	-2.630	-2.633	-2.635	-2.638	-2.640	-2.641	-2.804
Model without trend and with break (7^*)									
Significance level	τ_0	$\tau_0(\theta)$ with θ =							τ_c
		1998:08	1998:09	1998:10	1998:11	1998:12	1999:01	1999:02	
0.1%	-3.363	-3.835	-3.836	-3.834	-3.842	-3.848	-3.858	-3.852	-4.251
1%	-2.593	-2.918	-2.923	-2.929	-2.936	-2.942	-2.948	-2.950	-3.511
5%	-1.945	-2.092	-2.091	-2.099	-2.105	-2.111	-2.116	-2.117	-2.897
10%	-1.614	-1.675	-1.676	-1.681	-1.683	-1.686	-1.688	-1.691	-2.586
20%	-1.228	-1.238	-1.240	-1.241	-1.241	-1.243	-1.244	-1.243	-2.223

Fig. A3. Left-hand tails of cumulative distributions of τ-statistics for models with break



As might be expected, the cumulative distributions of $\tau_0(\theta)$ lie between the Dickey-Fuller distribution for models with and without the constant term. The distributions of $\tau_0(\theta)$ are also closer to that of τ_0 than τ_c. The distributions for the model with nonlinear trend and break, $\tau_{NL}(\theta)$, lie to the left of the relevant model without break. They still lie to the right of the distribution for the model with linear trend, however, except for low *p*-values (0.015 and smaller). In both cases, distributions for different break dates θ are very close to one another. Though plotted with thin lines, they are hardly distinguishable from each other in the figure.

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