

Trade Network Structure and Export Volatility

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1 Theoretical background

Xavier Gabaix (2011) offered theoretical and empirical evidence against the argument of Lucas (1977) that firm-specific shocks average out. Gabaix showed that 1/3 of output volatility in the United States can be directly tied to changes in the 100 largest U.S. firms. When firm sizes follow a power-law distribution, idiosyncratic shocks do not average out, and actually propagate downstream and affect aggregate economic output. This is because there are often few central suppliers for the key inputs to several industries. A shock to one the central firms causes consequences for all firms that require the input for their own production. I hypothesize that this relationship holds internationally, particularly given actual variation in the volume of exports by product and country, and the rise of international trade of intermediate goods due to global value chains. Equations that seek to attribute local fluctuations in exports to idiosyncratic shocks elsewhere in the world are estimated using two models.

2 Theoretical argument

Three basic points to my argument:

1. Countries need goods to produce goods (Leontief I-O linkages). Inputs from upstream suppliers are required to produce outputs for downstream consumers.
2. Countries role in the trade of individual goods (specifically their [centrality](#)) is not uniform, and for some goods, follows a power law distribution¹. The extent of this distribution varies from product to product, and can be captured for each product by applying the tools of network analysis.
3. Shocks from upstream are propagated downstream depending on the network structure for the affected product.

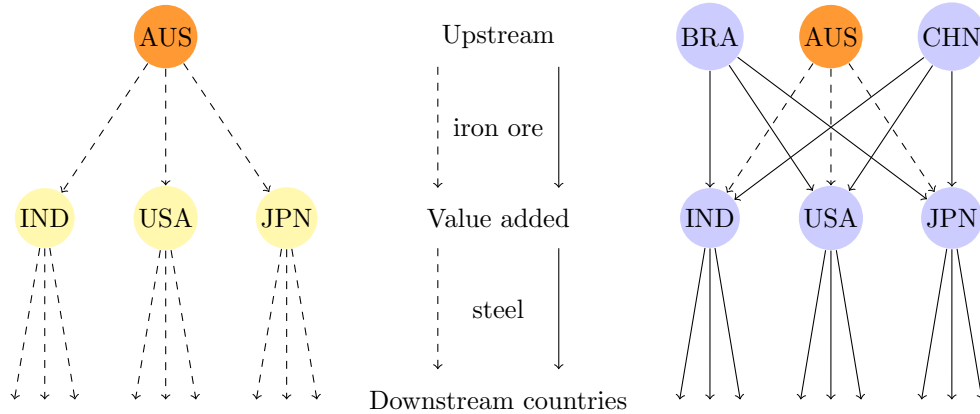
Essentially, this is an argument about how network structure affects whether idiosyncratic shocks propagate or die out. Internationally, does the trade network's tendency to have central exporters affect whether a supply-shock to the imports of an intermediate good are passed-through and reduce exports?

¹Defined for this paper as having an estimated alpha value of weighted outdegree centrality scores between 2 and 3, where $p(x) = Cx^{-\alpha}$.

The motivation for this research comes from an anomaly noticed following two recent natural disasters. First, the 2011 Tohoku earthquake and tsunami, which caused massive destruction, loss of life, and a nuclear disaster, also caused supply-shocks in global trade. French automakers were forced to shutter assembly lines after diesel engine imports from Japan were delayed. Likewise, the launch of the iPad 2 was delayed when the Japanese supplier of the cover glass was affected by the disaster. Second, the 2011 Thailand floods disrupted the production of computer hard disk drives, which has been dominated by Thai producers. The price of hard disk drives nearly doubled worldwide and remained elevated for two years. Such disruptions to the supply of key intermediate goods can create a situation where a localized supply-shock (from a natural disaster) results in aggregate fluctuations elsewhere in the world.

Visual representation: shock to central vs. non-central supplier

Figure 1: The effect of a negative shock to Australian iron ore exports depends on network structure. Here circles represent countries, with Australia (AUS) as the localized supply-shock affected country, in orange, countries without a functioning supplier in yellow, and unaffected countries in blue². Solid lines represent unaffected trade flows and dashed lines represent compromised trade flows.



3 Foundations in microeconomics

The derivation from theory of a testable hypothesis is borrowed almost verbatim from Acemoglu, Akcigit, and Kerr (2016) but adjusted to apply internationally (and to ignore demand shocks) as follows:

We start with a Cobb-Douglas production function for each country:

$$y_i = e^{z_i} l_i^{\alpha_i^l} \prod_{j=1}^n x_{ij}^{a_{ij}}$$

²There may still be price effects.

Where x_{ij} is the volume of goods produced by country j and imported to country i , l_i is labor, and z_i is a Hicks-neutral productivity shock. Assume that for each country, $\alpha_i^l > 0$, and $a_{ij} \geq 0$ for each pair of countries in the network (if $a_{ij} = 0$, there are no imports to country i from country j). Lastly,

$$\alpha_i^l + \sum_{j=1}^n a_{ij} = 1$$

so constant returns to scale are assumed.

The market clearing condition is:

$$y_i = c_i + \sum_{j=1}^n x_{ji}$$

where c_i is domestic consumption and an amount of goods is also exported to each of n countries.

The downward sloping line comes from preferences of a representative household:

$$u(c_1, c_2, \dots, c_n, l) = \gamma(l) \prod_{i=1}^n c_i^{\beta_i}$$

where β_i is distributed between 0 and 1, sums to 1 across all i 's, and represents the weight of goods from country i in the representative household's preferences. The disutility of labor is given by the function $\gamma(l)$, which is assumed to be negative.

The household faces the following budget constraint:

$$\sum_{i=1}^n p_i c_i = wl$$

where w is the wage rate, set to 1 for simplicity.

Aggregate profit maximization applied to the Cobb-Douglas production functions determines the individual good trade flows (assuming for simplification that trading costs are CIF and incorporated into p_j):

$$\frac{p_j x_{ij}}{p_i y_i} = a_{ij}$$

Consider therefore an international input-output matrix of a_{ij} 's denoted as \mathbf{A} :

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \dots \\ a_{21} & a_{22} & \\ \vdots & & \ddots \end{bmatrix}$$

The Leontief inverse of matrix \mathbf{A} is defined as:

$$\mathbf{H} \equiv (\mathbf{I} - \mathbf{A})^{-1}$$

with each entry in matrix \mathbf{H} identified as h_{ij} .

Acemoglu, Akcigit, and Kerr then propose the following relation for the impact of domestic and foreign shocks on changes to aggregate output:

$$d \ln y_i = \underbrace{dz_i}_{\text{own effect}} + \underbrace{\sum_{j=1}^n (h_{ij} - \mathbf{1}_{j=i}) \times dz_j}_{\text{network effect}}$$

where $\mathbf{1}_{j=i}$ is the indicator function for $j = i$.

4 Data sources and methods

The primary data source is the BACI dataset produced by CEPII. BACI provides data on bilateral trade by product at the HS six-digit level of disaggregation. BACI is essentially a cleaned and expanded version of UN Comtrade data.

Supply-shocks are identified using the EM-DAT database of natural disasters. Such supply shocks are by definition exogenous and location specific.

Data on total exports, the real effective exchange rate, and import and export prices ³ are obtained from the IMF's International Financial Statistics (IFS).

5 Testable hypothesis and econometric model

To test the theoretical relationship, I will use a variation on the empirical approach of Acemoglu, Akcigit, and Kerr, which is the analog to the previous equation, and specified as follows:

$$\Delta \ln Y_{i,t} = \delta_t + \psi \Delta \ln Y_{i,t-1} + \beta^{own} Shock_{i,t-1} + \beta^{upstream} Shock_{i,t-1} + \varepsilon_{i,t}$$

where δ_t is the time fixed effect and $\varepsilon_{i,t}$ is the error term.

So far, I've only slightly modified the theoretical model of Acemoglu, Akcigit, and Kerr. To make their empirical model fit with my hypothesis and the available data⁴, I will need to make additional changes, using two different approaches.

5.1 Imports decomposition model

- The model seeks to explain fluctuations in exports ($X_t - X_{t-1}$). The dependent variable is the change in the natural log of constant price exports of goods of country i in time t , given by $\hat{x}_{it} = \ln(X_t) - \ln(X_{t-1})$. Changes to exports offer insight into the downstream pass-through of an upstream (and in this case cross-border) supply shock. That is, a supply shock to a trading partner will have various domestic effects on consumption baskets and prices, but this work argues that to get to the heart of the question about whether shocks average out or propagate, we need to look at whether the downstream is affected.

³Import and export price indices are used to adjust nominal USD trade flow values to constant prices.

⁴HS 6-digit.

Table 1: Top ten power-law distributed goods by export value, 2014

HS code	USD value exports	Quantity in tons	No. of exporters	No. of importers	Estimated α	σ of estimate	Product Name
270900	14007.9	19936.2	116	141	2.43	0.36	Crude oil
271121	1810.5	3889.3	65	96	2.17	0.33	Natural gas
271111	1746.4	2514.9	63	98	2.18	0.34	Natural gas
740311	617.8	93.8	78	94	2.61	0.41	Cathodes
260300	536.2	238.2	83	81	2.22	0.36	Copper ore
853710	477.7	6.4	192	213	2.14	0.24	Electrical control boards
732690	411.3	89.1	196	216	2.30	0.29	Articles of iron/steel
901890	403.9	7.2	176	213	2.43	0.43	Instruments: medical
854430	364.3	15.9	134	191	2.29	0.32	Ignition wiring sets
840999	345.4	29.3	190	216	2.83	0.61	Misc. engine parts

Table 2: Top ten normally distributed goods by export value, 2014

HS code	USD value exports	Quantity in tons	No. of exporters	No. of importers	Estimated α	σ of estimate	Product Name
710812	2876.9	0.3	145	120	1.80	0.14	Gold
870323	2705.7	225.3	191	215	1.21	0.02	Medium sized cars
851712	2496.7	4.1	184	214	1.89	0.22	Cellular / wireless telephones
847130	1544.3	8.3	188	212	1.83	0.22	Laptop computers
854231	1478.8	2.1	154	194	1.17	0.01	Electronic integrated circuits
880240	1463.8	1.7	65	118	1.53	0.09	Aeroplanes & other aircraft
870332	1390.9	96.6	159	209	1.21	0.02	Small sized cars
870324	1260	56.9	175	210	1.28	0.03	Large sized cars
851762	1196.6	5.7	208	214	1.24	0.02	Telephone equipment
847330	1094.3	13	197	215	1.22	0.02	Computer parts and access.

- Next, to capture own (domestic) shocks, I control for changes to exchange rates and relative prices, as measured by the previous period change to the real effective exchange rate, \hat{q}_{t-1} . This is a domestic determinant of exports that is not correlated with the measures of network structure applied next.
- Lastly, to test the hypothesis that the distribution of exporter sizes affects whether supply shocks propagate or die out, it is critical to measure the upstream (foreign) shock and isolate different shocks by the network structure through which they arrive. This can be done by decomposing previous period intermediate⁵ goods imports into four categories, defined as follows:

Table 3: Categories of intermediate good imports, goods indexed by k

	central players	no central players
shock in time t	$M_{i,t-1}^{cs} = \sum_{k=1}^n M_{k,i,t-1}^{cs}$	$M_{i,t-1}^{ns} = \sum_{k=1}^n M_{k,i,t-1}^{ns}$
no shock	$M_{i,t-1}^{cn} = \sum_{k=1}^n M_{k,i,t-1}^{cn}$	$M_{i,t-1}^{nn} = \sum_{k=1}^n M_{k,i,t-1}^{nn}$

where M is the real US dollar value of imports to country i from all other countries. I aim to estimate the following equation:

$$\hat{x}_{i,t} = \delta_t + \beta_1 \hat{x}_{i,t-1} + \beta_2 \hat{q}_{i,t-1} + \beta_3 \ln M_{i,t-1}^{cs} + \beta_4 \ln M_{i,t-1}^{ns} + \beta_5 \ln M_{i,t-1}^{cn} + \varepsilon_{i,t}$$

where δ_t is again the time fixed effects. The second and third terms attempt to control

⁵All final consumption goods excluded to isolate products which can have downstream affects

for domestic shocks. Previous period export growth, $\hat{x}_{i,t-1}$, is unrelated to a next period supply shock, as is the previous period change in real effective exchange rate, $\hat{q}_{i,t-1}$. The variable of interest, which I hypothesize affects exports of downstream countries, is the previous period $(t-1)$ imports of goods with power law distribution exporter sizes when there has been a shock to the production of that good in period t , given by $\ln M_{i,t-1}^{cs}$. To control for the possibility that the supply-shock, regardless of exporter sizes, causes the full adjustment in exports, the non-power-law-distributed imports from supply shock countries are included as $\ln M_{i,t-1}^{ns}$. Lastly, to control for the possibility that exporter size distribution affects exports regardless of supply shocks, imports of goods where the exporter country sizes follow a power law distribution are included as $\ln M_{i,t-1}^{cn}$.

My hypothesis is then:

$$H_0 : \beta_3 < \beta_4, \quad \text{where: } \beta_3 < 0;$$

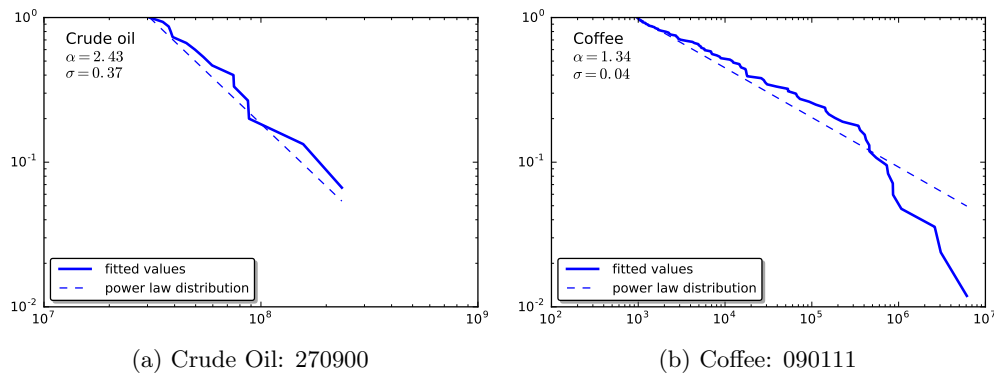
$$H_a : \beta_3 \geq \beta_4$$

5.2 Imports decomposition model: power law distribution

Figure 2 shows the complementary cumulative distribution function (CCDF) for the total export values by bilateral trading relationship of two goods in 2014. Both axes are in log scale. The vertical axis measures the probability that an individual export flow, X , is larger than x , the value on the horizontal axis. The horizontal axis measures the nominal USD value of exports in 2014. Coffee, picked by hand in many countries in a band surrounding the equator, does not experience central players in its trade network. As much as individuals may show preference for certain types of coffee, the size of suppliers is normally distributed.

Crude oil, the most traded good on earth, has a very public cartel. A few extremely large producers dominate the supply, while the demand side is also skewed towards the consumption-driven G8 economies. The result is a relatively small number of very large suppliers, which can be seen by the fit of figure 2a. The probability of the empirical result nearly always exceeds exact fit of a power law distribution. Theoretical predictions surrounding the power law distribution of supplier sizes for such a critical intermediate good are further explored in the second model.

Figure 2: Total exports and the price of oil



5.3 Imports decomposition model: estimation results

Two variations of the estimating equation were applied to a balanced panel of data covering 80 countries, with annual observations during 2008–2015. The first variation includes the previous period real export growth as a control variable to capture the domestic and network effects from the year prior to the external supply shock. The second variation of the estimating equation includes instead the previous period log-level of real exports as a control, to capture the convergence in growth rates between advanced and developing countries.

The estimated coefficients are presented in Table 4. The first two columns present the fixed effects within regression estimates, while the last two columns present the one-stage generalized method of moments (GMM) estimates. In all four models, the variable of interest, the previous period imports of goods with central suppliers from supply shock countries, is shown to be negative and statistically significant (M^{cs}). Each log unit of M^{cs} is estimated to reduce exports by between 2 and 12 percent in the following year, offering evidence that supply shocks can be transmitted through goods with fat-tail distributed suppliers. Supply shocks do not seem to transmit through goods with normally distributed exporter sizes, even when these goods are imported from countries with a supply shock (M^{ns}). An increased level of M^{ns} is shown to increase exports, with statistical significance varying by model.

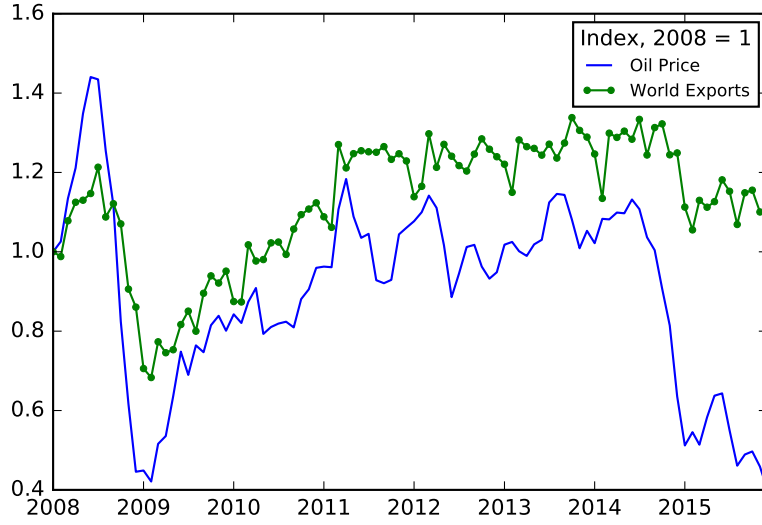
The domestic shocks to exports captured by previous period export values are shown to be statistically significant and may be capturing trends such as a convergence in export growth rates. The previous period changes to the real effective exchange rate are not shown to be statistically significant in the models below.

Table 4: Estimation results (\hat{x}_{it}): Import decomposition model

	FE1	FE2	GMM1	GMM2
	(1)	(2)	(3)	(4)
\hat{x}_{it-1}	-.495 (0.041)***		-.118 (0.05)**	
x_{it-1}		-.253 (0.047)***		-.107 (0.058)*
\hat{q}_{it-1}	-.009 (0.139)	-.002 (0.155)	0.765 (0.675)	0.655 (0.66)
M_{it-1}^{cs}	-.021 (0.01)**	-.036 (0.011)***	-.104 (0.03)***	-.117 (0.027)***
M_{it-1}^{ns}	0.051 (0.015)***	0.029 (0.017)*	0.129 (0.039)***	0.102 (0.036)***
M_{it-1}^{cn}	0.017 (0.022)	-.069 (0.022)***	0.13 (0.05)***	0.03 (0.026)
N	560	560	560	560
adj. r^2	0.732	0.67		
F	146.968	111.162		
χ^2			956.42	1066.001
$\sigma^2(\varepsilon_{it})$			0.044	0.039

Significance levels : * : 10% ** : 5% *** : 1%

Figure 3: Total exports and the price of oil



5.4 Oil price shocks model

The second model focuses on the role of one specific good, crude oil, in the propagation of shocks through network effects. Through foundations in microeconomics, we identified domestic shocks and network shocks as determinate of fluctuations in output. In the previous model, we decomposed imports by trade partner supply shock and product supplier size distributions to identify the role of exogenous shocks in domestic disturbances. The oil price shocks model instead assumes all network effects shocks to be conveyed by shocks to the price of oil.

The price of oil is determined globally by supply and demand and not within any one set of borders, therefore can be considered exogenous. While oil is component in transportation, and therefore trade costs, the use in this model of the oil price is to reflect external shifts in supply and demand. The oil price shock measure, which is high-frequency and not location-specific, is applied to monthly data on total trade, from the IMF's Direction of Trade Statistics (DOTS).

The estimation equation is:

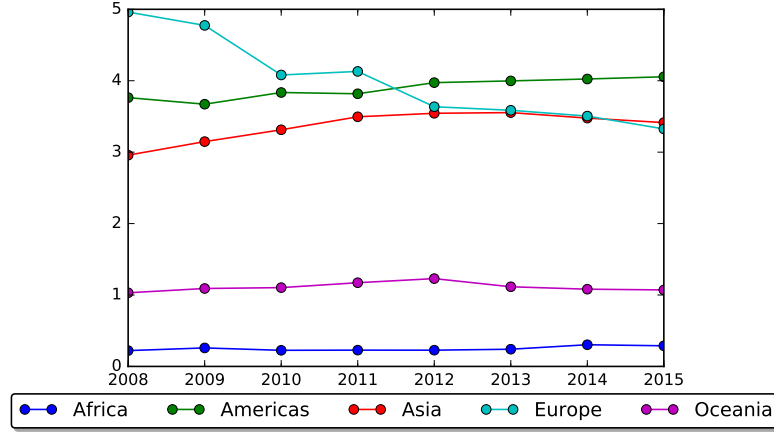
$$\hat{x}_{i,t} = \delta_t + \beta_1 x_{i,t-1} + \beta_2 \hat{q}_{i,t-1} + \beta_3 (c_{it} \times \hat{\rho}_t) + \varepsilon_{i,t}$$

where c_{it} is the eigenvector centrality of imports and $\hat{\rho}_t$ is the change in most recent month change in the price of crude oil. The centrality term follows a similar algorithm to the pagerank algorithm used by Google, where, in the case of imports, the number and size of import flows is important, but the relative importance of your suppliers is also taken into consideration. The term is meant to measure how critical each country is in each month to the global trade network, with particular focus on the susceptibility of its imports to central suppliers. The interaction between the centrality term and the oil price term is meant to capture the mechanism through which an exogenous shock enters (the centrality to global imports) and the exogenous shock itself (a change in oil prices). Table 4 shows trends around the largest exporters of goods.

Table 5: Measures of Real Exports by Country (25 largest exporters shown)

Country Name	2015 Real Exports USD, billion	Real Export Growth since 2008	Export Growth Volatility ($\sigma^2(\bar{x}_{it})$)	Eigenvector Centrality of Exports Rank 2008	Eigenvector Centrality of Exports Rank 2015	Change in Centrality of Exports since 2008
China	2307.97	0.82	0.23	1	1	0.08
United States	1514.26	0.34	0.17	2	2	0.02
Germany	1224.68	-0.14	0.20	3	3	-0.04
Japan	506.32	-0.25	0.22	4	4	-0.05
France	467.13	-0.15	0.20	8	8	-0.04
Italy	448.01	-0.05	0.23	11	11	-0.03
United Kingdom	422.77	-0.09	0.23	10	10	-0.03
Netherlands	391.46	-0.20	0.26	7	9	-0.05
Belgium	369.06	-0.14	0.24	12	14	-0.04
Canada	351.46	-0.12	0.31	5	6	-0.04
Mexico	341.42	0.34	0.29	9	7	0.05
Singapore	308.25	0.07	0.25	23	22	0.00
Russian Federation	303.69	-0.16	0.38	14	15	-0.04
Spain	251.34	-0.06	0.23	19	23	-0.01
Malaysia	201.93	0.32	0.25	15	12	0.01
Switzerland	187.55	0.10	0.21	18	18	0.00
Poland	177.32	0.24	0.24	30	26	0.00
Czech Republic	149.28	0.21	0.23	31	28	0.00
Brazil	149.09	0.03	0.38	17	17	0.00
Australia	138.78	0.27	0.41	16	13	0.01
Austria	137.91	-0.12	0.22	25	27	-0.01
Saudi Arabia	135.28	-0.37	0.66	13	19	-0.05
Sweden	117.68	-0.38	0.26	28	31	-0.02
Norway	83.30	-0.48	0.46	24	33	-0.03
Hungary	79.96	-0.24	0.22	39	35	0.00

Figure 4: Average eigenvector centrality score of imports by continent



5.5 Oil price shocks model: estimation results

Estimation results for the oil price shocks model are consistent with a hypothesis that shocks transmitted through central suppliers are propagated. The results, however, are not very robust and seem driven primarily by the time trend captured through time fixed effects and the oil price shock. Additional specifications of this model will be needed, as FE1 illustrates. The monthly time series suggests a lagged effect on trade from oil price shocks. Additionally, the centrality scores vary little over time, and therefore are not well specified in a model with time fixed effects.

Table 6: Estimation results (\hat{x}_{it}): Oil price shocks model

	FE1	FE2	FE3
	(1)	(2)	(3)
x_{it-1}	-.159 (0.008)***	-.116 (0.007)***	-.169 (0.008)***
\hat{q}_{it-1}	0.007 (0.082)	0.126 (0.091)	0.005 (0.081)
$(c_{it} \times \hat{\rho}_t)$	-.235 (0.193)	1.140 (0.191)***	
c_{it}			1.369 (0.182)***
$\hat{\rho}_t$			0.969 (0.123)***
$\hat{\rho}_{t-1}$	2.316 (0.278)***		
N	5076	5076	5076
adj. r^2	0.256	0.049	0.265
F	19.78	105.394	20.571

Significance levels : * : 10% ** : 5% *** : 1%

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