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March 2010

DYNAMIC OLS ESTIMATION OF THE U.S. IMPORT DEMAND FOR MEXICAN CRUDE OIL

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ABSTRACT

This paper estimates the U.S. import demand for crude oil from Mexico. The analysis is based on time series from January 1990 to December 2010. Time series properties of the processes that generate the data are assessed in order to specify the order of integration for each series. According to results from unit root tests, all the series under study are unit root non-stationary. The paper then estimates the cointegrating import demand regression using Dynamic OLS procedure. Residuals from the DOLS cointegrating regression are tested and found to be stationary; thus, the cointegrating regression is not spurious. According to estimation results, U.S. import demand for Mexican crude oil is income inelastic, perfect price inelastic, and responsive to changes in both U.S. stock of oil (excluding SPR) and unemployment rate in the U.S. Also, this paper points to the estimate bias from omitting relevant variables as it is common in the mainstream literature on crude oil import demand.

Keywords*: Crude Oil Demand, Unit Root, Dynamic OLS.*

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1. INTRODUCTION

This paper focuses on one of the most important items in the U.S.-Mexico relationship. U.S. and Mexico are major trade partners of each other; U.S. is the main trade partner to Mexico whereas Mexico is the top third trade partner to the U.S. –next to Canada and China. Crude oil is a major commodity in U.S.-Mexico trade. In 2009, Mexico became the second largest supplier of crude oil to the U.S. –next to Canada. In 2010, U.S. imported 3,344 millions of crude oil barrels from around the world, out of those 416 millions of crude oil barrels came from Mexico –i.e., 12.44 percent. On the other hand, Mexico exports of crude oil to the U.S. amounted to 83 percent of its total exports in 2010. Even more, in 2010 oil related revenues represented 38 percent of the public sector total revenues in Mexico. Therefore, the assessment of the determinants of U.S. import demand for Mexican crude oil is of the most importance to both the U.S. and Mexico. Indeed, a prior assessment was not found in the literature.

The paper is divided into seven sections, including this one. Section 2 reviews the literature on import demand functions, in particular, on crude oil import demand. Section 3 introduces the crude oil import demand function that this paper estimates whereas section 4 presents the corresponding data set. Section 5, then, discusses the methodology that is followed while section 6 shows estimation results. Finally, section 7 concludes.

2. LITERATURE REVIEW.

Import demand functions are commonly specified as a typical demand function; that is, the import demand for a commodity is modeled as a function of aggregate income in the importer country and the relative price of the imported commodity; other determinants of demand may also be included– Anaman and Buffong (2001), Agbola and Damoense (2005), Masih (2000), Masih and Masih (2000), Mah (2000), Sinha (1997), Thursby and Thursby (1984). In addition, import demand regressions are log-linear. Thus, parameter estimates are elasticity estimates of the import demand with respect to its determinants.

Agbola and Damoense (2005) estimate import demand functions for pulses in India, which have as explanatory variables real per capita GDP, relative price of imports, and degree of urbanization. Similarly, Anaman and Buffong (2001) estimate an aggregate import demand for Brunei that includes as regressors the import prices index, the domestic price, real gross domestic product, and population. Nonetheless, it is also common that import demand regressions are specified as a function of aggregate income and relative price only –Mah (2000), Masih (2000), Masih and Masih (2000), Sinha (1997), Thursby and Thursby (1984).

Literature on import demand estimation used to be questioned on two grounds, the lack of microeconomic foundations for its assumed demand function specification, and the failure to assess the times series properties of the data used. Senhadji (1998) provides the microeconomic foundations for the traditional specification of import demand equations. Also, now the literature on import demand function analyzes time series properties of the data and chooses the estimation method accordingly.

Literature on crude oil import demand estimation follows from previous discussion. Crude oil import demand function are commonly specified to include as regressors aggregate income and relative price only –Al-Azzam and Hawdon (1997), Carone (1996), Ghosh(2009), Melo and Vogt (1984), Uri and Boyd (1988), Ziramba (2010). Only most recent literature on crude oil imports performs time series analysis of the variable under study –Al-Azzam and Hawdon (1997), Carone (1996), Ghosh(2009), Ziramba (2010).

As a result of its parsimonious specification of the import demand function for crude oil, the literature is constrained to report income and price elasticities. Ziramba (2010) includes a detailed account of elasticity estimates in the literature; overall, crude oil import demand is both price and income inelastic. Although there are exceptions; for instance, Gosh (2009) finds that India's crude oil import demand is income elastic whereas the price elasticity estimate is statistically insignificant.

Finally, Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests are common in the literature. In addition, Stock-Watson Dynamic OLS has been used to estimate cointegrating import demand regressions –Al-Azzam and Hawdon (1997), Masih (2000), Masih and Masih (1996).

3. CRUDE OIL IMPORT DEMAND

This paper models the crude oil import demand as a function of its own price relative to the price of substitute goods –i.e., crude oil from other countries and natural gas–, aggregate income, and the need that the importer country has for crude oil in terms of its current stock of it and to fuel its domestic economic activities.

$$ln M = f(ln Y, ln P, ln PG, ln Stock, ln Un) \quad (1)$$

where,

M, U.S. crude oil imports from Mexico

Y, U.S. aggregate income

P, U.S. import price of Mexican crude oil relative to the average import price from all countries

PG, U.S. import price of Mexican crude oil relative to the wellhead price of natural gas in the U.S.

Stock, U.S. stock of crude oil

Un, U.S. unemployment rate

This specification follows the literature on commodity import demand and, in particular, crude oil import demand. However, it must be noticed that it is common in the literature on crude oil import demand to include as regressors aggregate income and price only. In contrast, in order to avoid biased estimates as a result of omitted relevant variables, the crude oil import demand in this paper includes relevant regressors in addition to aggregate income and price.

Crude oil is a normal good, thus, one expects that an increase in aggregate income in the U.S. would increase its demand for crude oil, including Mexican crude oil; i.e., $f_Y > 0$. Also, one would expect that the higher the price of Mexican crude oil imports relative to the price of substitute goods –e.g., crude oil from other countries and natural gas–, the less of Mexican crude oil would be imported; i.e., $f_P < 0$, $f_{PG} < 0$. Similarly, the more the U.S. needs of crude oil, the larger its crude oil imports. In particular, one would expect that a drop in U.S. stock of crude oil would signal a greater need and, thus, U.S. imports of crude oil would increase, including Mexican crude oil; i.e., $f_{Stock} < 0$. Similarly, a drop in the unemployment rate would signal an increase in economic activity, which in turn would increase U.S. needs of crude oil and thus increase U.S. crude oil imports, including Mexican crude oil; i.e., $f_{Un} < 0$.

4. DATA SET

The analysis in this paper is based on seasonally adjusted monthly time series that start on January 1990 and end on December 2010. Table 1 below details how each variable of study is measured and the corresponding data source. Table 2, in turn, shows the descriptive statistics for each series. On the other hand, table 3 presents partial correlation coefficients that show no evident concern regarding multicollinearity; in particular, notice that aggregate income and unemployment rate convey different information.

Table 1: Description of Variables

Variable	Definition	Measurement	Source
M	U.S. imports of Mexican crude oil	thousands of crude oil barrels per day	Sistema de Información Energética
Y	U.S. personal income	billions of chained 1982-1984 U.S. dollars	Bureau of Economic Analysis
P	price of U.S. crude oil imports from Mexico relative to the average price of U.S. crude imports from around the world	Index: (U.S. Import price of Mexican crude oil, in U.S. dollars per barrel) / (U.S. Average Import price of crude oil from around the world, in U.S. dollars per barrel)	Sistema de Info. Energética / Energy Info. Administration
PG	price of U.S. crude oil imports from Mexico relative to the wellhead price of natural gas in the U.S.	Index: (U.S. import price of Mexican crude oil, in U.S. dollars per barrel) / (U.S. average wellhead price of natural gas, in U.S. dollars per thousand cubic feet)	Sistema de Info. Energética / Energy Info. Administration
Stock	U.S. Ending Stocks (excluding Strategic Petroleum Reserves, SPR) of Crude Oil	thousands of barrels	Energy Information Administration
Un	U.S. unemployment rate	percentage points	Bureau of Labor Statistics

Table 2: Descriptive Statistics

	M	Y	P	PG	Stock	Un
Mean	7.04	8.46	2.73	2.09	12.68	1.74
Median	7.09	8.51	2.57	2.07	12.69	1.72
Maximum	7.47	8.67	3.92	3.20	12.84	2.32
Minimum	6.44	8.21	1.66	1.16	12.52	1.35
Std. Dev.	0.23	0.16	0.51	0.36	0.07	0.23
Skewness	-0.68	-0.24	0.51	0.46	-0.24	0.72
Kurtosis	2.53	1.63	2.51	3.20	2.34	3.00
Jarque-Bera	21.65	22.24	13.37	9.38	7.01	21.62
Probability	0.00	0.00	0.00	0.01	0.03	0.00
Sum	1773.88	2131.81	687.34	526.25	3195.01	437.41
Sum Sq. Dev.	12.95	6.06	64.06	33.15	1.28	13.85
Observations	252	252	252	252	252	252

Table 3: Correltion Matrix

	M	*Y*	*P*	*PG*	*Stock*	*Un*
M	1	0.69673	0.17467	-0.3891	-0.5293	-0.4397
Y	0.69673	1	0.68694	0.08032	-0.2475	-0.0722
P	0.17467	0.68694	1	0.53256	0.00118	0.23468
PG	-0.3891	0.08032	0.53256	1	0.43424	0.57334
Stock	-0.5293	-0.2475	0.00118	0.43424	1	0.4342
Un	-0.4397	-0.0722	0.23468	0.57334	0.4342	1

Figure 1: Scatter diagrams, Oil Imports against each regressor.

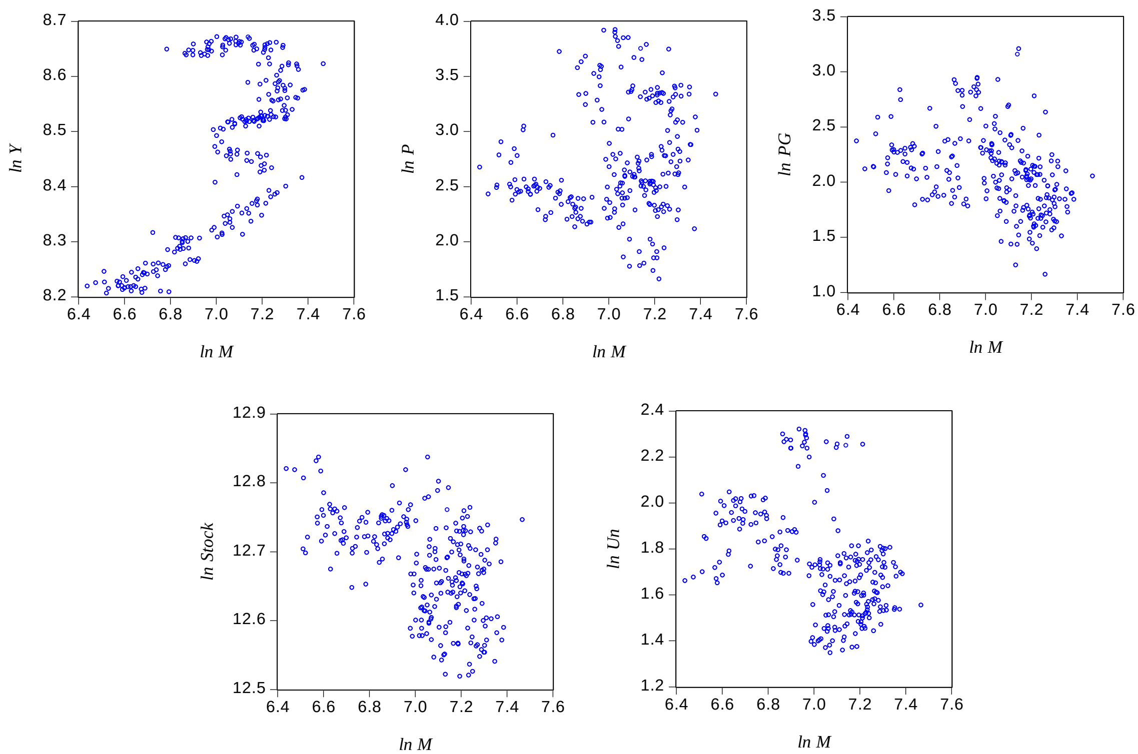

Figure 1, on the other hand, includes scatter diagrams where U.S. imports of Mexican crude oil is plotted against each of the regressors. One can infer from these scatter diagrams the expected negative relationship between crude oil imports and the import price of Mexican crude relative to natural gas, the stock of crude oil, and the unemployment rate. However, it is not so evident the expected negative relationship between crude oil imports and the import price of Mexican crude oil relative to the average import price of crude. On the other hand, one can infer the expected positive relationship between crude oil imports and personal income.

Of course, the comments above are based on simple visual inference. We need to estimate the import demand equation in order to, first, evaluate whether the expected and visual relationships are statistically significant and, then, estimate the actual effect that a regressors has on U.S. import demand for Mexican crude oil.

5. METHODOLOGY: TIME SERIES ANALYSIS

The goal of this paper is to estimate U.S. import demand function for Mexican crude oil. However, in order to prevent estimating a spurious regression, the time series properties of the variables of study are determined before the estimation procedure is chosen. Augmented Dickey-Fuller (ADF), Phillips-Perron

(PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests are performed on each series to determine their order of integration. Results from unit root tests would determine the procedure to be employed to estimate the U.S. import demand for Mexican crude oil. For instance, if all series are integrated of order 0, then ordinary least squares procedure (OLS) may be used; in contrast, if series are unit root non-stationary, then OLS would render a spurious regression.

The ADF unit root test involves estimating regression (2) for each series and, then, testing the null hypothesis of a unit root, H_0: $\alpha = 0$, versus the alternative of a stationary process, H_1: $\alpha < 0$. The test is based on the typical t-ratio for α –Fuller (1976), Dickey and Fuller (1979). However, the t-statistic does not follow the t-distribution under the null; thus, critical values are simulated for each regression specification and sample size –MacKinnon (1996).

$$\Delta y_t = \alpha y_{t-1} + x_t^{'}\delta + \sum_{p=1}^{p} \Delta y_{t-p} + \varepsilon_t \qquad (2)$$

x_t, exogenous regressors that may include a constant term only, a constant and a trend, or none.

Δy_{t-p}, terms included to correct for higher-order correlation.

The PP unit root test involves estimating a non-augmented version of regression (2); i.e., without the lagged difference terms. PP unit root test uses a non-parametric method to control for serial correlation under the null hypothesis. H_0 and H_1 are the same as in the ADF test; however, PP unit root test is based on its own statistic and corresponding distribution –Phillips (1987), Phillips and Perron (1988).

The KPSS test, in contrast to ADF and PP tests, assumes that the series is stationary under the null. KPSS tests the OLS residuals obtained from equation (3) –where x_t is defined as in equation (2)– based on a LM statistic.

$$y_t = x_t^{'}\delta + \varepsilon_t \qquad (3)$$

Provided all series are I(1) –as they are in this case–, then DOLS procedure is employed to estimate the single cointegrating vector that characterizes the long-run relationship among the variables in the U.S. import demand function for Mexican crude oil: “one simply regress one of the variables –Mexican crude oil imports, in this case– onto contemporaneous levels of the remaining variables, leads and lags of their first differences, and a constant, using” ordinary least squares. (Stock and Watson, 1983, p. 784.)

Stock-Watson DOLS model is specified as follows:

$$Y_t = \beta_0 + \vec{\beta}X + \sum_{j=-q}^{p} \vec{d}_j \Delta X_{t-j} + u_t \quad (4)$$

Y_t dependent variable

X matrix of explanatory variables

$\vec{\beta}$ cointegrating vector; i.e., represent the long-run cumulative multipliers or, alternatively, the long-run effect of a change in X on Y

p lag length

q lead length

Lag and lead terms included in DOLS regression have the purpose of making its stochastic error term independent of all past innovations in stochastic regressors. Finally, unit root tests are performed on the residuals of the estimated DOLS regression, in order to test whether it is a spurious regression. "In the unit-root literature, a regression is technically called a spurious regression when its stochastic error is unit-root nonstationary." (Choi et. al., 2008, p. 327.) Unit root tests and DOLS estimation are performed using EViews 7.

6. DYNAMIC OLS ESTIMATION RESULTS

Results from unit root tests show that all the series under study are unit root non-stationary –See table 4. In particular, all specifications of ADF and PP tests cannot reject the null hypothesis of a unit root process –at a .10 significance level– for all variables in level except *Un*. In the case of *Un* in level, only the PP unit root test with a drift can reject the null hypothesis of a unit root process at a .10 significance level; i.e., the null hypothesis cannot be rejected in the case of *Un* in level according to both ADF test specifications and PP test with drift and constant. When the series in first difference are tested, the null hypothesis of a unit root process is rejected –at least at a .10 significance level- according to all specifications of ADF and PP tests. Therefore, ADF and PP unit root tests conclusively show that all variables of study are I(1). KPSS stationarity tests further confirm such conclusion. That is, according to KPSS tests results, the null hypothesis of a stationary process can be rejected for the series in level, but cannot be rejected for the series in first difference.

Table 4: Unit Root Tests, ADF, PP, and KPSS

Test Statistic by Unit Root Test			Variables					
			M	*Y*	*P*	*PG*	*Stock*	*Un*
	ADF: drift	Level	-2.43	-1.52	-0.04	-0.036	-1.87	-1.9
		1st diff.	-28.64	-3.09	-8.04	-15.05	-4.48	-3.02
			***	**	***	***	***	**
	ADF: drift & trend	Level	-1.57	-1.39	-1.97	-0.59	-1.67	-1.88
		1st diff.	-28.62	-3.35	-8.07	-15.07	-4.56	-3.16
			***	*	***	***	***	*
	PP: drift	Level	-2.41	-0.9	-0.01	-0.49	-2.05	-2.59
								*
		1st diff.	-417.85	-97.95	-16.32	-46.57	-57.91	-33.90
			***	***	***	***	***	***
	PP: drift & trend	Level	-2.54	-2.06	-2.06	-0.85	-2.07	-2.42
		1st diff.	-336.71	-64.71	-10.55	-15.08	-52.14	-31.67
			***	***	***	***	***	***
	KPSS: drift	Level	1.17	2.00	1.38	0.43	0.43	0.30
			***	***	***	*	*	
		1st diff.	0.19	0.18	0.15	0.28	0.11	0.27
	KPSS: drift & trend	Level	0.41	0.31	0.38	0.39	0.33	0.30
			***	***	***	***	***	***
		1st diff.	0.05	0.12	0.03	0.06	0.02	0.11

Notes: H_0: Unit root process for ADF and PP; in contrast, H_0: stationary process for KPSS;
*, **, *** refers to the rejection of H_0 at .10, .05, .01 significance level, respectively;
number of lags in ADF tests is selected according to modified AIC.

Given that all the series in the U.S. import demand function for Mexican crude oil are unit root non-stationary; then, the cointegrating regression to be estimated is the following:

$$\begin{aligned} ln\, M_t = \beta_0 + \beta_1 \ln Y + \beta_2 \ln P + \beta_3 \ln PG + \beta_4 \ln Stock + \beta_5 \ln Un + \sum_{j=-q}^{p} \vec{d}_1 \Delta \ln Y_{t-j} + \\ \sum_{j=-q}^{p} \vec{d}_2 \Delta \ln P_{t-j} + \sum_{j=-q}^{p} \vec{d}_3 \Delta \ln PG_{t-j} + \sum_{j=-q}^{p} \vec{d}_4 \Delta \ln Stock_{t-j} + \sum_{j=-q}^{p} \vec{d}_5 \Delta \ln Un_{t-j} + u_t \end{aligned} \quad (5)$$

The cointegrating regression that includes aggregate income and price as the only regressors is estimated too. This specification is the one that commonly appears in the literature on crude oil import demand. Table 5 presents DOLS estimation results. The number of leads and lags were selected according to the Akaike information criterion.

Estimation results show that, for the full specification of the crude oil import demand –DOLS 1–, both relative prices are statistically insignificant whereas the rest of parameters are statistically significant. Therefore, the U.S. import demand for Mexican crude oil is perfectly inelastic with respect to both relative prices. In other words, an increase in the price of Mexican crude oil imports relative to the average U.S.

crude oil imports price, or relative to the wellhead price of natural gas in the U.S., does not affect U.S. imports of Mexican crude oil at all.

Table 5: DOLS Estimation Results

	β_0		β_1		β_2		β_3		β_4		β_5	
DOLS 1	40.5720	***	0.5611	**	0.1198		0.1462		-2.9951	***	-0.5137	**
	(7.09)		(2.07)		(1.20)		(0.82)		(-7.81)		(-2.20)	
DOLS 2	-7.7599	***	1.8129	***	-0.2248	***						
	(-11.46)		(21.27)		(-6.67)							

	R^2	Adj. R^2	S.E.	D.W.	SSR	Leads	Lags
DOLS 1	0.9696	0.8886	0.0683	1.6541	2.2880	15	15
DOLS 2	0.8185	0.7878	0.1066	0.8256	0.2800	15	0

Notes: ***, **, * denotes statistical significance at 1, 5, and 10%, respectively; t-statistics appears in parenthesis; leads & lags selected according to AIC.

Table 6: Unit Root / Stationarity Tests on Residuals from DOLS 1 and DOLS 2

		ADF				PP				KPSS		
		drift		drift & trend		drift		drift & trend		drift	drift & trend	
DOLS 1 Residuals	level	-6.35	***	-6.34	***	-12.56	***	-12.53	***	0.03	0.03	
	1st diff.											
DOLS 2 Residuals	level	-2.22		-2.16		-8.86	***	-8.85	***	0.12	0.12	*
	1st diff.	-25.63	***	-25.60	***						0.08	

Notes: H_0: Unit root process for ADF and PP; in contrast, H_0: stationary process for KPSS.
*, **, *** refers to the rejection of H_0 at .10, .05, .01 significance level, respectively

On the other hand, the U.S. import demand for Mexican crude oil is income inelastic; i.e., a 1 percent increase in U.S. disposable income would cause a 0.5611 percent increase in U.S. imports of Mexican crude oil. U.S. imports of Mexican crude oil are also sensitive to changes in the U.S. need of crude oil. That is, if U.S. stock of oil –excluding SPR– decreases by 1 percent, then U.S. imports of Mexican crude oil would increase by 2.99 percent. Similarly, if the unemployment rate in the U.S. drops by 1 percent, then U.S. imports of Mexican crude oil would increase by 0.5137 percent.

In contrast, according to DOLS 2 cointegrating regression –i.e., the typical specification of the crude oil import demand–, both regressors aggregate income and relative price are statistically significant. The estimated income elasticity of the U.S. import demand for Mexican crude oil is 1.8129, which is more than three times the income elasticity estimated from DOLS 1. The estimated price elasticity is -0.2248; thus, an increase in the relative price of Mexican crude oil by 1 percent would cause a decrease by 0.2248 percent in the U.S. imports of Mexican crude oil.

Nonetheless, estimates from DOLS 2 specification are biased, since it excludes relevant regressors such as *Stock* and *Un*. In addition, all specifications of ADF, PP and KPSS units root tests conclude that residuals from cointegrating regression DOLS 1 are stationary –see table 6. Therefore, cointegrating regression DOLS 1 is not a spurious regression. On the other hand, both PP and KPSS unit root tests conclude that residuals from DOLS 2 are stationary; however, ADF unit root tests concludes that such residuals are unit root non-stationary.

7. CONCLUDING REMARKS

This paper focuses on one of the most important items in the U.S.-Mexico relationship. Mexico provides secure and reliable supply of crude oil to the U.S. In return, Mexico receives revenues to finance its public sector. This paper specifies the U.S. import demand for Mexican crude oil as function of aggregate income, Mexican crude oil import price relative to the average crude oil import price and relative to the wellhead natural gas price, stock of crude oil, and the unemployment rate.

According to estimation results, U.S. import demand for Mexican crude oil is perfect price inelastic –i.e., elasticity estimates are not statistically significant different from zero. That is, the U.S. continues buying Mexican crude oil even if its price increases above its competitors'; i.e., crude oil from other countries or natural gas. On the other hand, U.S. import demand for Mexican crude oil is income inelastic and the same sensitivity is shown with respect to changes in the U.S. unemployment rate. In addition, U.S. import demand for Mexican crude oil is elastic to changes in the U.S. stock of crude oil –excluding SPR.

Mexico has an opportunity to collect rents from the U.S., since it is insensitive to changes in the relative price of Mexican crude oil. On the other hand, given that most of its crude oil exports go to the U.S., Mexico faces the risk of not raising enough oil related revenue when the economic growth in the U.S. decreases or its stock of oil increases.

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