Title

Trucks, Trains and Climate Change: Emissions of CO_2 and Criteria Pollutants from U.S. - Mexico Overland Freight

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Trucks, Trains and Climate Change
Emissions of CO_2 and Criteria Pollutants from U.S. – Mexico Overland Freight

by

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List of Acronyms

BTS	Bureau of Transportation Statistics
CO_2	Carbon Dioxide
CO	Carbon Monoxide
EPA	U.S. Environmental Protection Agency
FTAA	The Free Trade Agreement of the Americas
GATT	General Agreement on Tariffs and Trade
NAFTA	The North American Free Trade Agreement
NO_X	Nitrogen Oxides
PM10	Particulate Matter 10 microns or less
VOC	Volatile Organic Compounds

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Chris Jones

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1. Introduction

Each month the equivalent of 50 pounds of goods is imported an average of 1,250 miles from Mexico to the United Sates for each U.S. household. An average of 80 pounds of goods is imported roughly the same distance for each Mexican household. This is an increase of roughly 140% over levels in 1994, when the North American Free Trade Agreement (NAFTA) went into effect.

Critics of economic globalization have pointed to air emissions from of an ever increasing volume of international freight transport as an unmistakable side-effect of a globalized economy. With transportation accounting for roughly one third of greenhouse gas emissions, and freight accounting for a third of transportation, the increasing distance goods are shipped could have a dramatic impact on global warming, in addition to an unhealthy increase in localized criteria (or conventional) pollutants. This threat is recognized by critics of globalization who call for trade to be more localized. For example, the International Forum on Globalization published the following statement in its book 2002 book, "Alternatives to Economic Globalization: A Better World is Possible":

> *"It could be argued that the most important single act to improve the health of the planet and the quality of urban life would be to lessen the volume of international and long-distance transport. This goal can only be achieved by consciously reversing present priorities favoring large-scale export-oriented global economies…"*[1]

[1] IFG, 2002. Page 165. The International Forum on Globalization defines this book, "Alternatives to Economic Globalization: A Better World is Possible", as "the Definitive Document from the Anti-Corporate Globalization Movement". They define themselves as "an alliance of leading activists, scholars, economists, researchers and writers-representing 60 organizations in 25 countries- that was formed in 1994 to stimulate new thinking, joint activity, and public education in response to economic globalization".

This statement underscores the importance freight transport plays in a globalized economy and the potential of increasing international trade to generate concern over air emissions from the transport of freight.

To study the effect of trade liberalization on air emissions from freight transport, this study models trade flows between the United States and Mexico since implementation of the North American Free Trade Agreement (NAFTA) and emissions of carbon dioxide and criteria pollutants from the transport of freight between the two countries. The goal is to analyze the potential of increasing trade to impact air emissions from freight transport. It should be noted, however, that the high volume of goods exchanged along this border by truck, one of the most highly polluting modes of transport, may make this example unrepresentative of trade agreements that encourage freight transport by other, less polluting, modes. It is also very difficult (or impossible) to discern the effect of any particular trade agreement on the flow of freight since many other factors may lead to changes in trade (including the effect of other agreements, e.g. the GATT in this case). The approach then is simply to provide an estimate of changes in emissions, rather than to model the portion of those emissions directly attributable to NAFTA.

The results roughly confirm what many see to be a clear and significant increasing source of greenhouse gases. As the value of goods traded between Mexico and the U.S. has increased by roughly 180% (or 130% in real terms), CO_2 emissions have increased by around 150%. Thus, changes in the value of trade, which is easily tracked and understood, serves as a good rough indicator of changes in levels of CO_2 from freight transport. On the other hand, the total volume of greenhouse gases from U.S. – Mexico freight transport amounts to less than 1% of mobile source emissions and only about 0.2% of total CO_2 emissions from the U.S. economy[2]. This study also finds that while NO_X and particulate matter have increased, CO and VOC emissions have decreased over this period. Thus, improvements in truck technology have, in some cases, been able to outpace the increase in increase in freight shipments. Differences in CO_2 and criteria pollutant emissions are compared over time, by U.S. and Mexican states, by sector of the economy and by transport mode.

These values have not previously been calculated due to the poor quality of freight data available to researchers. Specifically, ton-miles, a common metric of freight activity, are not publicly available. This study produces estimates of ton-miles for the years 1993 to 2003 for all commodities shipped between the United States and Mexico for truck and rail. It is hoped that these data will be useful for future transportation and trade studies.

[2] Author's calculation from model data.

2. Methods

The model constructed for this study is extensive, covering all overland (truck and rail) imports and exports between the United States and Mexico from 1993 to 2003. In total, the model contains some 15 million individual data points and 14 variables (commodity type, transport mode, year, U.S. State, Mexican State, value, weight , miles, ton-miles, carbon dioxide (CO2), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter -10 microns or less (PM10).

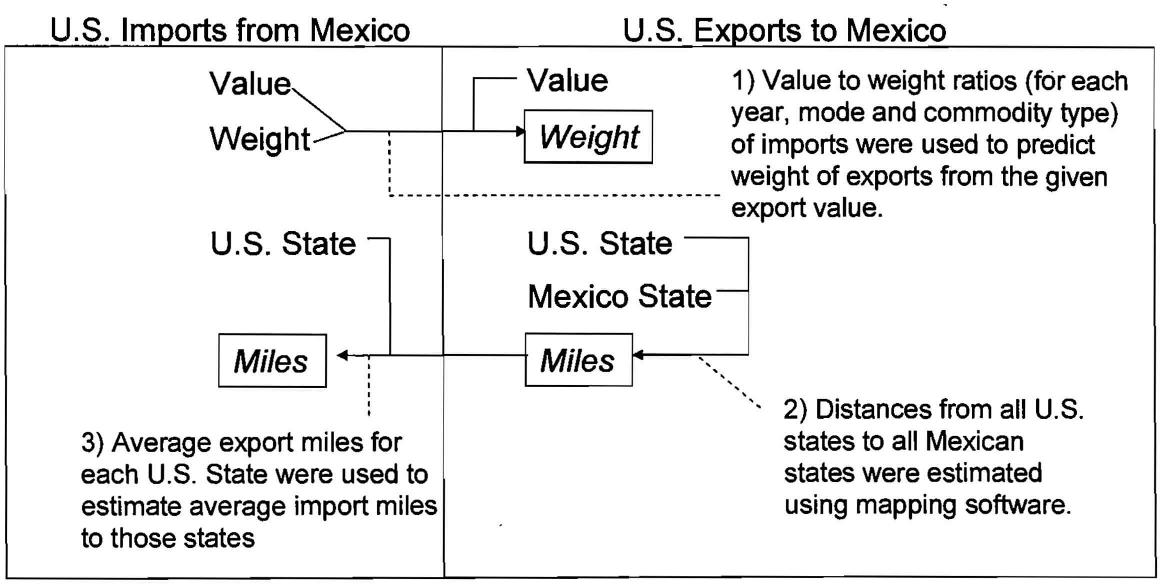
This model uses tradeflows provided by the Bureau of Transportation Statistic's North America Transborder Freight database[3] to estimate ton-miles (and subsequently air emissions) of freight shipments between Mexico and the United States from 1993 to 2003. Ton-miles are a common metric of freight activity, yet they are not publicly available for freight shipments between these countries. This is because the data freight carriers are required to provide U.S. customs officials is insufficient to estimate ton-miles without such a modeling effort. Specifically, in the BTS database, U.S. exports to Mexico include the value of goods shipped, but not the weight of goods, while U.S. imports from Mexico include the U.S. destination of goods, but not the Mexican origin data. This study attempts to fill these holes by using import data to predict missing export data, and export data to predict missing import data. Ton-miles are then used to estimate greenhouse gas and criteria air pollutants emitted from truck and rail transport modes.

Figure 2.1.1 demonstrates the methods used to estimate missing import and export data. First, the value to weight ratios (for each year, mode and commodity type) of imports were used to predict the weight of exports from the given export value. Second,

[3] Bureau of Transportation Statistics. http://www.bts.gov/programs/international/transborder/

distances from all U.S. states to all Mexican states were estimated using mapping software. The average export miles from each U.S. state were then used to estimate the average import miles to those same states.

Figure 2.1.1 Map of Methods Used to Estimate Missing U.S. – Mexico Freight Data



Finally, air emissions were estimated using U.S. inventories of greenhouse gases[4], criteria pollutants[5] and ton-miles[6] from truck and rail modes. These methods were applied to the roughly one million entries in the BTS database such that each entry contains year, transport mode, commodity type, U.S. State, Mexico State (exports only), value, weight, miles, ton-miles, CO_2, CO, NOx, VOC and PM. A detailed explanation of this methodology follows.

[4] EPA, 2005.
[5] Ibid.
[6] BTS, 2005a.

2.1 Estimating Export Weight

Regression analysis was applied to the value to weight ratios (sum of value divided by the sum of weight) of imports for each of the 98 NAIC (North American Import Code) commodity groups, for rail and truck modes, for the years 1997 through 2003. Linear regression was typically used, although cubic, reciprocal, and exponential plots, as well as the mean, were used where the fit was deemed most appropriate. In all cases, the regression plots were weighted by the shipping weight for each year so outliers (typically based on years with low volume of goods) did not greatly affect the analysis. These years were then used to predict value to weight ratios for 1993 through 1996 since import data for weight are not given by the BTS Transborder Freight database. Finally, the weight of exports was estimated by dividing the value of exports by the predicted value to weight ratios from the regression analysis of imports. This is considered to be a reasonable assumption since low tariffs can be expected to keep average prices competitive between the two countries, particularly for manufactured goods, which comprise over 60% of goods by value traded between the two countries (see results, section 4 below).

2.2 Estimating Miles

Origin and destination states were given by the BTS Transborder Freight database for exports. The first step in estimating the total miles for each shipment was to estimate the expected shipping routes from all U.S. states to all Mexican states. The online mapping software Mappoint, provided by Microsoft at http://mappoint.msn.com, was used to determine these distances. The state capitols of U.S. and Mexican states were used as starting and ending points for states since these are normally central locations within states and, in the case of Mexico, they are usually large cities. There was one exception;

the city of Bakersfield was chosen for California since Sacramento is significantly north of most manufacturing areas.

The high volume of goods shipped to and from Texas and California (50% by weight in 2003) presents two complications. First, much of this trade can be expected to be between sister cities along the border, suggesting that the choice of Houston and Bakersfield might overestimate miles for these states. Second, and more importantly, a significant volume of goods is known to be marked by customs agents as originating in the border state of crossing, although the contents may have come from other states further from the border. The vehicles sector is a good example of this. According the BTS database, Texas now exports more vehicles by weight than Michigan, despite the fact that there are no major auto assembly plants in Texas. The over-recording of California and Texas shipments would account for the unusually high volume of goods from those states in the database. Additionally, Transborder shipping does not include the distance parts or ingredients travel before becoming part of final products. Overall, the total miles estimated in this study can be considered likely a low, but best guess estimate based on the available data.

2.3 Estimating Air Emissions

Emissions of CO_2 and criteria pollutants per ton-mile were determined by assuming that emissions per ton-mile in U.S. - Mexico freight transport are similar to emissions per ton-mile in U.S. domestic shipping. Emissions can be affected by a number of factors including the technology of vehicles, the volume vs. weight of products shipped, the percentage of empty loads, road conditions, driving behavior, idling time etc. Rather than estimating emissions from a bottom-up approach, that would require taking all of these variables into consideration, a top-down approach based on U.S. inventories of air emissions[7] and ton miles[8] for truck and rail modes was used. This approach also has the advantage of being able to track the change in emissions over time. Table 2.1.1 summarizes the emissions factors for the years under study.

Table 2.1.1 Emissions factors (grams per ton-mile)

Trucks	1990	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
CO2	209	222	218	218	221	220	222	226	235	237	230	240
CO	9.48	7.13	6.23	5.50	4.91	4.28	4.04	4.03	2.58	1.97	1.88	1.77
Nox	3.39	3.46	3.36	3.32	3.34	3.29	3.23	3.08	3.15	2.72	2.51	2.50
VOC	0.67	0.50	0.44	0.39	0.35	0.30	0.29	0.30	0.19	0.17	0.15	0.15
PM	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Rail	**1990**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
CO2	33.3	30.7	29.0	27.3	26.5	26.6	25.8	25.6	24.8	24.6	23.6	24.7
CO	0.81	0.79	0.75	0.71	0.69	0.69	0.67	0.61	0.59	0.57	0.55	0.56
Nox	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06
VOC	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.02
PM	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

These factors were checked against other published estimates of emissions on a ton-miles basis and found to be fairly consistent (see table 2.2), despite the mix of calculation methods and study areas. Basing emissions factors on the U.S. government inventory was deemed to be the best way to bypass these many methodological issues.

Table 2.2.1 Emissions factors vs. other published studies (grams per ton-mile)

Trucks	Ang-Olson[a]	OECD[b]	Europe[b]	mean	Jones[c]
CO	0.68	0.40	3.84	1.64	2.58
CO2	151	224	331	235	235
Nox	1.54	4.80	5.76	4.03	3.15
PM	0.09	0.27		0.18	0.15
VOC	0.13		1.76	0.94	0.19

Rail	AAR[d]	Jones[c]
CO2	26	26

[a] Ang-Olson, 1999. Calculated from output tables for San Antonio - Hermosillo corridor
[b] OECD, 1997. Table 9.
[c] Author's estimate for year 2000
[d] ARA. 2005. Calculated from table 1.

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[7] EPA, 2005.
[8] BTS, 2005a. Table A-1.

2.4 Corrections in the Modeling

Several changes to the BTS Transborder Freight database between 1993 and 1997 had to be addressed in the modeling. First, data were only available for April through December of 1993 as previous data were not published. Also, since this was the first year reporting was required, the BTS Transborder Freight reliability files for that year note that unreported shipments were as high as 50% in April of 1993 but fell to 15% by December of that same year. To compensate for the low volume of shipments reported in that year, a multiplier of 1.46 was applied to all shipments. This was the ratio of the value of goods officially reported by the BTS[9] for that year to the value of goods in the database. Data for 1993, therefore, were a sample of roughly 50% of total goods shipped, rather than a record (or census) of all goods shipped. A second correction was made for the weight of imports for 1993-1996, which was not given in the database. For these years the value to weigh ratios predicted by regression analysis described above were used to estimate the weight for those years.

2.5 Reliability and Weaknesses of the Model

Limitations in the modeling approach were primarily due to the lack of data, and at times the poor quality of data collected by U.S. customs officials. Primary weaknesses in the database include non-specific destination and origin data, over estimation of goods shipped from border states, lack of weight data for U.S. exports and lack of origin data for U.S. imports. This study has attempted to compensate for these defects as a best approach given the limitations in the data. Because of the limitations in the data,

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[9] BTS, 2005(2). Figure 1.

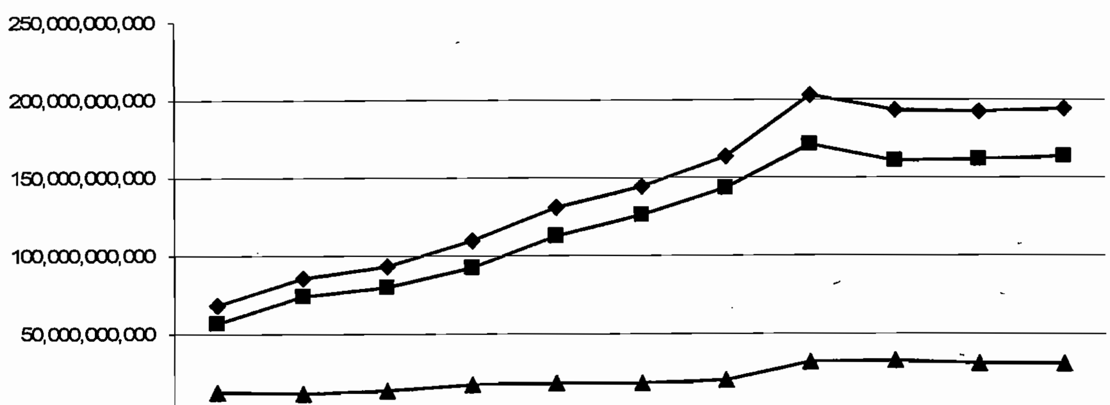
particularly in the origin and destination of shipments, a best guess is that the true value may be as much as 20% higher than these estimates. As a result, total air emissions can also be expected to be higher than the predicted values, although the trend, or the change in emissions over time, is likely to be quite accurate. The earlier years in the model, particularly 1993, are most subject to error. As shown in the following section, however, the results for 1993 are roughly consistent with long term trends. In fact, they appear to be consistent enough to draw comparisons between 1993 (as apposed to a later year) and 2003, i.e. pre-NAFTA and a decade after its implementation.

3. Results

3.1 Value of U.S. Mexico Trade

The total value of goods shipped between the United States and Mexico roughly tripled between 1993 and 2003, from US$69 billion in 1993 to US$194 billion in 2003. In real (inflation adjusted) dollars, the increase was 2.3 fold. This translates to a 12% annual increase, although the value of goods increased by 17% annually between 1993 and 2000. Trade dramatically flattened in 2001 and remained under 2000 values for the following two years. Shipments by truck increased more rapidly than shipments by rail, growing by 188% and 154% respectively, or 12% vs. 11% annual growth.

Figure 3.1.1 Value of U.S. Trade with Mexico, 1993-2003 (US$)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	68,653,3	86,041,4	93,198,8	109,858,	130,604,	144,534,	163,775,	202,609,	193,046,	192,452,	194,052,
Truck	56,467,5	74,080,4	79,366,4	92,441,7	112,309,	126,315,	143,371,	171,057,	160,600,	161,518,	163,085,
Rail	12,185,7	11,961,0	13,832,3	17,416,9	18,294,9	18,218,4	20,404,0	31,551,9	32,446,1	30,933,6	30,966,6

Texas accounted for fully one-third of all U.S. – Mexico trade, followed significantly by California (17%) and Michigan (14%). In total, these three states were responsible for 64% of all shipments by value. The vast majority of trade from California and Texas was by truck (96% and 91% respectively) while most trade from Michigan by value (58%) was by rail.

Table 3.1.1 Value of U.S. Trade with Mexico by U.S. State, 2003 (US$)

	Rail	%	Truck	%	Total	%
TX	58,258,960,670	36%	5,760,452,836	19%	64,019,413,506	33%
CA	32,442,522,654	20%	1,295,661,164	4%	33,738,183,818	17%
MI	11,230,093,071	7%	15,476,687,957	50%	26,706,781,028	14%
IN	4,996,379,882	3%	1,346,888,503	4%	6,343,268,385	3%
AZ	5,915,567,307	4%	209,342,752	1%	6,124,910,059	3%
IL	5,161,999,409	3%	886,009,856	3%	6,048,009,265	3%
OH	5,354,628,516	3%	665,140,714	2%	6,019,769,230	3%
TN	3,183,880,131	2%	755,664,188	2%	3,939,544,319	2%
NY	3,671,032,951	2%	234,281,411	1%	3,905,314,362	2%
NC	3,831,047,864	2%	72,944,754	0%	3,903,992,618	2%
Other	29,028,415,796	18%	4,263,275,868	14%	33,291,691,664	17%
Total	163,074,528,251	100%	30,966,350,003	100%	194,040,878,254	100%

The manufacturing sectors dominated the value of goods shipped between the two countries. Including vehicles, manufactured goods accounted for roughly 60% of all shipments. The distribution of goods by sector in 2003 was roughly similar to the distribution of goods in 1993, with manufacturing the highest, followed by agriculture and textiles. Heavy, low value goods such as stone and minerals accounted for the lowest trade by value. The sectors experiencing the highest growth over 1993 values were textiles (268%), vehicles (228%) and plastics (257%). The slowest growing sectors were wood products (95%) and minerals (75%).

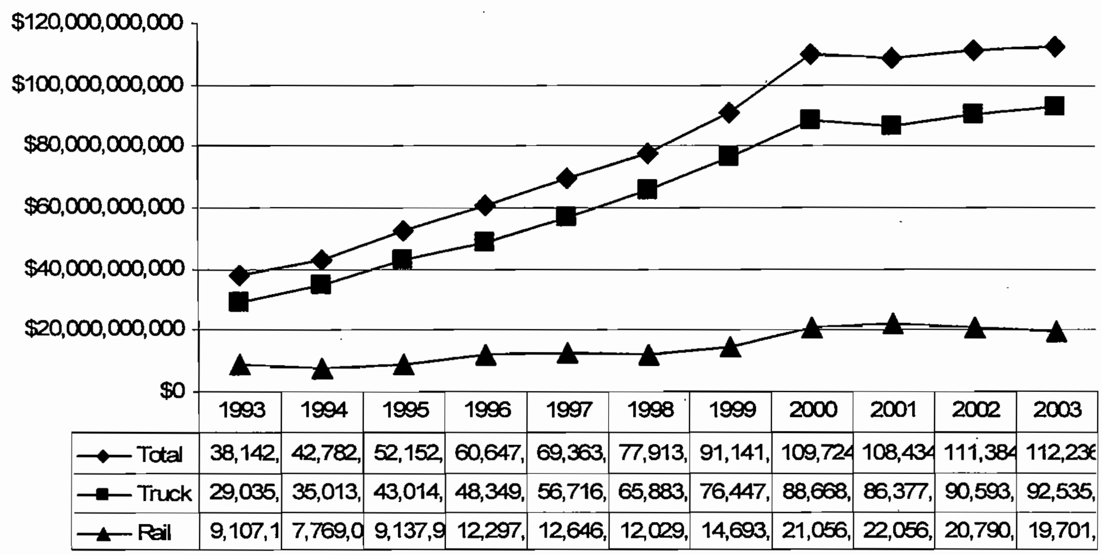
Table 3.1.2 Value of U.S. Trade with Mexico by Sector, 1993-2003 (US$)

	1993	%	2003	%	% Change
Manufactured goods	28,274,526,168	41%	81,006,942,324	42%	187%
Vehicles & parts	9,861,392,247	14%	32,363,281,406	17%	228%
Other	8,082,774,395	12%	21,868,033,719	11%	171%
Agriculture	6,072,143,143	9%	13,344,452,876	7%	120%
Textiles	3,421,380,788	5%	12,584,654,213	6%	268%
Plastics	2,838,872,797	4%	10,145,437,462	5%	257%
Metal products	4,006,179,434	6%	9,852,102,237	5%	146%
Chemicals	2,041,441,731	3%	5,218,146,493	3%	156%
Wood products	2,428,201,614	4%	4,237,450,960	2%	75%
Stone & ceramic	880,712,343	1%	2,360,349,245	1%	168%
Minerals	550,027,400	1%	1,071,637,745	1%	95%
Total	68,457,652,059	100%	194,052,488,680	100%	183%

Value of U.S. Imports from Mexico

The value of U.S. imports from Mexico paralleled the value of trade overall, essentially tripling from 1993 to 2003, and growing at an average of 12% annually. From 1993 to 2000 trade increased by 18% annually, but stopped growing abruptly in 2001. In contrast to U.S. exports to Mexico (see section below), there was no noticeable modal shift between rail and trucking during this period, with trucking increasing by 218% and rail increasing by 216%.

Figure 3.1.2 Value of U.S. Imports from Mexico (US$)



U.S. imports from Mexico are heavily dominated by Texas, Michigan and California. These three states accounted for over 60% of U.S. Imports from Mexico in 2003. The modal choices for freight transport appear to be highly determined by the distance the freight must travel, with rail dominating long-distance shipping and trucks dominating shorter distances. Fully 93% of Texas' shipping by value is carried by trucks, while 62% of Michigan's shipping by value is carried by rail. Eighty-three percent of all U.S. imports from Mexico are shipped by truck.

Table 3.1.3 2003 Value of U.S. Imports from Mexico to Top 10 U.S. States (US$)

US State	trucks	%	Rail	%	Total	%
TX	23,789,844,514	26%	1,658,429,164	8%	25,448,273,678	23%
MI	8,743,925,256	9%	14,073,918,864	71%	22,817,844,120	20%
CA	19,441,607,515	21%	1,051,101,879	5%	20,492,709,394	18%
IN	4,242,118,108	5%	75,192,962	0%	4,317,311,070	4%
IL	3,568,152,294	4%	550,344,442	3%	4,118,496,736	4%
OH	3,966,628,608	4%	45,628,786	0%	4,012,257,394	4%
AZ	2,976,874,920	3%	94,844,936	0%	3,071,719,856	3%
NC	2,628,454,392	3%	45,178,669	0%	2,673,633,061	2%
NY	2,542,560,955	3%	24,559,202	0%	2,567,120,157	2%
TN	2,120,377,866	2%	437,044,077	2%	2,557,421,943	2%
Total	92,535,039,373	100%	19,701,679,154	100%	112,025,430,777	100%

Despite the notion that NAFTA has encouraged the U.S. to send its manufacturing jobs to Mexico, heavy manufacturing consisted of the same percentage of U.S. imports in 1993 as in 2003, at 62% (including manufactured goods and vehicles). The manufactured goods sector, in fact, grew slightly less than goods overall at 183% compared to 196% for all goods. The industries with the highest growth were textiles (303%), plastics (254%) and vehicles (224%). Agricultural imports and heavy items such as minerals, stone and wood, experienced lower than average growth. Minerals increased by only 40% from 1993 values and wood increased by 87%. Agricultural imports from Mexico increased by 136%, but decreased as a percentage of total imported good by value.

Table 3.1.4 Value of U.S. Imports from Mexico by Sector in 1993 & 2003 (US$)

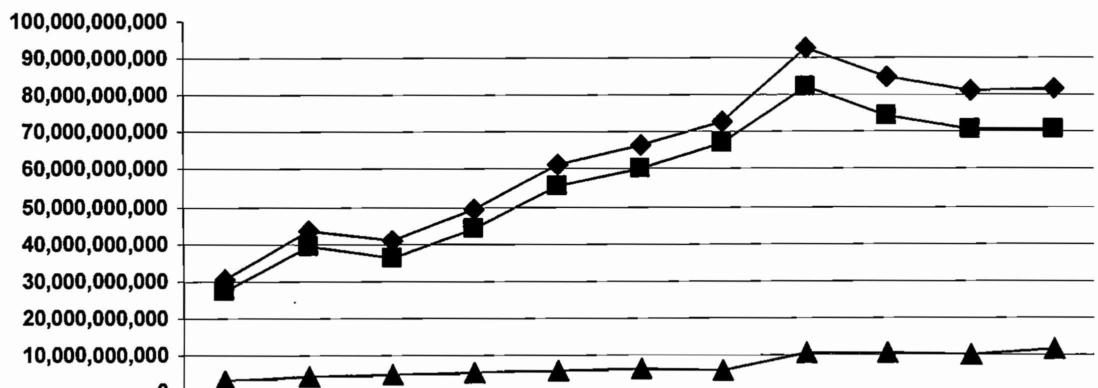
	1993	%	2003	%	% Change
Manufactured goods	16,836,693,415	44%	47,683,716,893	42%	183%
Vehicles & parts	7,011,119,712	18%	22,722,663,538	20%	224%
Other	5,221,306,133	14%	16,634,890,653	15%	219%
Textiles	1,932,242,736	5%	7,786,834,681	7%	303%
Agriculture	2,932,073,587	8%	6,909,560,378	6%	136%
Metal products	1,626,277,871	4%	4,251,852,492	4%	161%
Plastics	587,692,365	2%	2,079,225,540	2%	254%
Stone & ceramics	598,958,906	2%	1,602,685,836	1%	168%
Chemicals	516,501,788	1%	1,347,292,885	1%	161%
Wood products	549,249,515	1%	1,028,820,506	1%	87%
Minerals	134,766,216	0%	189,175,125	0%	40%
Total	37,946,882,245	100%	112,236,718,527	100%	196%

Value of U.S. Exports to Mexico

The value of U.S. exports to Mexico increased by 168%, which is less than the 196% U.S. imports from Mexico increased. This is evidence of the much touted increasing U.S. trade deficit with Mexico since the implementation of NAFTA. There was a slight modal shift in favor of rail over this time frame, with rail increasing by 166% compared to a 157% increase of goods exported by truck. Nonetheless, 86% of goods continued to be shipped by truck in 2003 compared to 14% by rail.

Just as the value of goods imported to the United States depends on the strength of the U.S. economy, the value of U.S. goods exported to Mexico depends on the strength of the Mexican economy. Figure 3.1.3 shows the dip in goods shipped to Mexico during the Mexican peso crisis of 1995. Mexican imports quickly recovered in 1996 and continued with an average growth rate of 18% from 1996 through 2000. Interestingly, the U.S. economic slump of 2001-2003 appears to have had more of an effect on exports to Mexico, which decreased in 2001 and 2002, than on U.S. imports from Mexico, which remained essentially unchanged in 2001 and increased in 2002. This suggests that consumer spending in Mexico was more vulnerable to the economic downturn than in the United States. As of 2003, the value of U.S. exports to Mexico had yet to recover.

Figure 3.1.3 Value of U.S. Exports to Mexico (US$)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	30,510,	43,258,	41,046,	49,211,	61,240,	66,620,	72,634,	92,885,	84,612,	81,067,	81,815,
Truck	27,432,	39,066,	36,352,	44,091,	55,592,	60,432,	66,923,	82,389,	74,223,	70,924,	70,550,
Rail	3,078,5	4,192,0	4,694,4	5,119,2	5,648,0	6,188,7	5,710,6	10,495,	10,389,	10,143,	11,264,

U.S. exports to Mexico are highest for Texas and California, accounting for 47% and 16% of exports to Mexico respectively, or 63% total. The top ten U.S. exporting states accounted for 84% of all exports in 2003. Exports of goods from Michigan accounted for only 5% of the total in contrast to 20% of the value of imports. Eighty-six percent of exports were shipped by truck and 14% by rail.

Mexican states receiving U.S. exports of goods were significantly more evenly distributed with seven Mexican states importing more goods than the third largest U.S. exporter (Michigan). Six of the top Mexican importing states are border states, accounting for 63% of total Mexican imports by value. Mexico City and its surroundings imported 22% of U.S. goods by value. Chihuahua was the largest single importing state at 22%. The top 10 importing Mexican states account for 93% of all imports to Mexico from the United States with 86% shipped by truck.

Table 3.1.5 2003 Value of U.S. Exports to Mexico from Top 10 U.S. States (US$)

US State	Truck	%	Rail	%	Total	%
TX	34,469,116,156	49%	4,102,023,672	36%	38,571,139,828	47%
CA	13,000,915,139	18%	244,559,285	2%	13,245,474,424	16%
MI	2,486,167,815	4%	1,402,769,093	12%	3,888,936,908	5%
AZ	2,938,692,387	4%	114,497,816	1%	3,053,190,203	4%
IN	754,261,774	1%	1,271,695,541	11%	2,025,957,315	2%
OH	1,387,999,908	2%	619,511,928	5%	2,007,511,836	2%
IL	1,593,847,115	2%	335,665,414	3%	1,929,512,529	2%
TN	1,063,502,265	2%	318,620,111	3%	1,382,122,376	2%
NY	1,128,471,996	2%	209,722,209	2%	1,338,194,205	2%
NC	1,202,593,472	2%	27,766,085	0%	1,230,359,557	2%
Other	10,525,271,645	15%	2,618,099,327	23%	13,143,370,971	16%
Total	70,550,839,672	100%	11,264,930,481	100%	81,815,770,153	100%

Table 3.1.6 2003 Value of U.S. Exports to Mexico to Top 10 Mexican States (US$)

Mexico State	Truck	%	Rail	%	Total	%
CH	17,176,812,476	24%	442,001,443	4%	17,618,813,919	22%
MX	8,106,065,167	11%	2,421,232,315	21%	10,527,297,482	13%
BC	9,832,722,075	14%	156,882,180	1%	9,989,604,255	12%
TM	7,589,411,264	11%	93,663,192	1%	7,683,074,456	9%
CO	4,613,705,630	7%	2,734,277,431	24%	7,347,983,061	9%
DF	6,084,273,622	9%	1,091,951,362	10%	7,176,224,984	9%
NL	5,021,471,138	7%	706,971,176	6%	5,728,442,314	7%
JA	2,807,206,441	4%	979,272,614	9%	3,786,479,055	5%
SO	2,994,852,939	4%	389,489,993	3%	3,384,342,932	4%
GT	1,768,970,992	3%	1,200,291,330	11%	2,969,262,322	4%
Other	4,555,347,928	6%	1,048,897,445	9%	5,604,245,373	7%
Total	70,550,839,672	100%	11,264,930,481	100%	81,815,770,153	100%

Manufacturing dominates U.S. exports, accounting for 41% of the total. The vehicles sector (which includes vehicles and parts) is also significant, accounting for 12% of U.S. exports, or US$9.6 billion. While large, this is less half of the US$22 billion of vehicles and parts imported to the U.S. from Mexico. The balance of trade for the textile industry is also heavily tilted in Mexico's favor totaling US$7.8 billion in U.S. imports, compared to US$4.8 billion in U.S. exports. U.S. agricultural exports to Mexico at US$6.4 billion roughly equal agricultural imports from Mexico at US$6.9 billion.

Total U.S. exports to Mexico were 268% higher in 2003 than in 1993, although they more than tripled if only considering the time period from 1993 to 2000. The plastic and rubber sector experienced the highest growth at 258%, while the wood products sector was the lowest at 71% growth over 1993 values.

Table 3.1.7 Value of U.S. Exports to Mexico by Sector in 1993 & 2003 (US$)

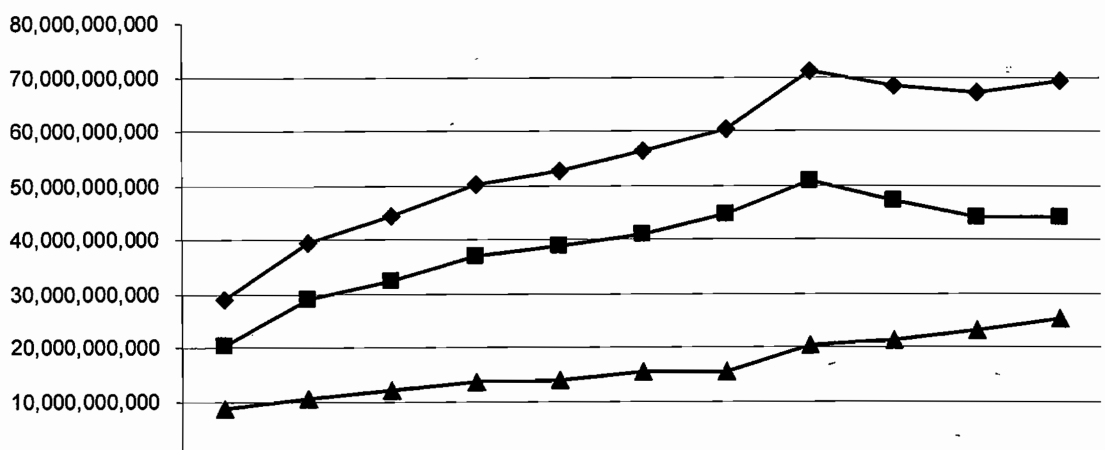
	1993	%	2003	%	% Change
Manufatured goods	11,437,832,753	37%	33,323,225,431	41%	191%
Vehicles	2,850,272,534	9%	9,640,617,868	12%	238%
Plastic	2,251,180,432	7%	8,066,211,922	10%	258%
Agriculture	3,140,069,556	10%	6,434,892,498	8%	105%
Metal	2,379,901,563	8%	5,600,249,745	7%	135%
Other	2,861,468,263	9%	5,233,143,066	6%	83%
Textiles	1,489,138,052	5%	4,797,819,532	6%	222%
Chemicals	1,524,939,943	5%	3,870,853,608	5%	154%
Wood	1,878,952,098	6%	3,208,630,454	4%	71%
Minerals	415,261,184	1%	882,462,620	1%	113%
Stone	281,753,436	1%	757,663,409	1%	169%
Total	30,510,769,814	100%	81,815,770,153	100%	168%

3.2 Weight

The weight (or "volume") of goods shipped between the United States and Mexico increased by roughly 140% between 1993 and 2003. This compares to growth by value of

180% (or 130% in real adjusted dollars) and growth by ton-miles of 166%. Growth was steeper in earlier years than later years of the study, although the impact of the economic crisis of 2001 had less effect on weight as it did on value. This is explained by a steady increase in the volume of exports of agricultural goods by rail during this period (see below). As a result, there was an important modal shift in the weight of goods, with rail increasing as a percentage of goods shipped during the slow economic growth years. While exports by truck decreased by 16% during this period, exports by rail increased by 9%. Furthermore, in 1993 rail represented 30% of trade by weight, while in 2003 rail represented 36% of trade by weight.

Figure 3.2.1 Weight of U.S. - Mexico Trade, 1993-2003 (kg)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	28,846,	39,412,	44,417,	50,191,	52,730,	56,265,	60,179,	71,009,	68,179,	67,146,	69,140,
Truck	20,381,	28,936,	32,360,	36,798,	38,838,	40,910,	44,721,	50,836,	47,031,	44,095,	43,929,
Rail	8,465,2	10,476,	12,056,	13,392,	13,892,	15,354,	15,458,	20,172,	21,148,	23,050,	25,210,

In 2003, Texas accounted for 36% of total trade by weight, more than double the trade by California, the next largest state. Together, Texas and California accounted for fully half of trade by weight with 75% of this trade occurring by truck. Midwestern agricultural states such as Iowa and Nebraska shipped the majority of their freight by rail (96% in the case of Nebraska and 90% in the case of Iowa.

Table 3.2.1 Weight of U.S. Trade with Mexico by U.S. State (kg)

	Truck	%	Rail	%	Total	%
TX	16,891,245,026	38%	8,162,066,500	32%	25,053,311,526	36%
CA	8,601,101,397	20%	1,023,318,329	4%	9,624,419,726	14%
MI	1,903,646,053	4%	2,672,812,453	11%	4,576,458,506	7%
AZ	2,885,078,805	7%	373,621,773	1%	3,258,700,578	5%
IL	1,431,253,325	3%	1,539,289,393	6%	2,970,542,718	4%
IA	200,228,872	0%	1,748,299,167	7%	1,948,528,039	3%
NE	63,298,751	0%	1,449,313,259	6%	1,512,612,010	2%
PA	617,652,951	1%	845,871,039	3%	1,463,523,990	2%
OH	1,161,668,600	3%	301,575,141	1%	1,463,243,741	2%
GA	758,064,586	2%	496,934,513	2%	1,254,999,098	2%
Other	9,412,550,460	21%	6,596,949,118	26%	16,009,499,578	23%
Total	43,925,788,825	100%	25,210,050,685	100%	69,135,839,511	100%

Agricultural goods accounted for 26% of goods shipped in 1993 and increased to 29% of total goods by 2003 with growth of 161% over this time period. Other high growth sectors include textiles (319%), plastics (273%), vehicles (223%), and manufactured goods (160%).

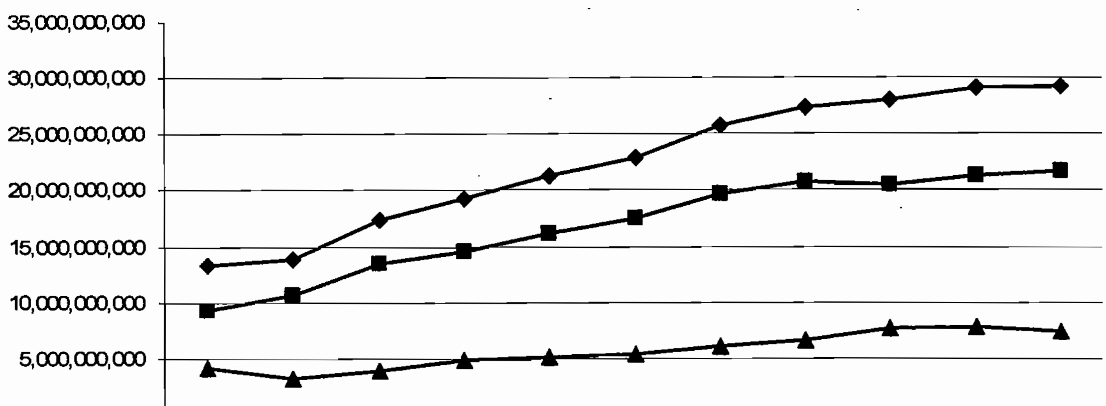
Table 3.2.2 Weight of U.S. Trade with Mexico by Sector, 1993 & 2003 (kg)

	1993	%	2003	%	% Change
Agriculture	7,556,105,049	26%	19,705,584,448	29%	161%
Manufactured goods	3,457,899,411	12%	8,987,561,482	13%	160%
Metal products	3,500,416,452	12%	7,390,827,489	11%	111%
Minerals	3,359,580,128	12%	6,119,972,347	9%	82%
Vehicles & parts	1,820,985,882	6%	5,879,521,111	9%	223%
Plastics	1,346,779,786	5%	5,020,042,077	7%	273%
Wood products	3,106,619,305	11%	4,658,876,208	7%	50%
Chemicals	1,693,440,189	6%	4,108,234,959	6%	143%
Stone & ceramic	1,220,586,984	4%	2,907,875,138	4%	138%
Other	1,339,703,985	5%	2,301,885,658	3%	72%
Textiles	491,494,947	2%	2,059,991,830	3%	319%
Total	28,893,612,118	100%	69,140,372,747	100%	139%

Weight of U.S. Imports from Mexico

The total weight of U.S. imports from Mexico increased by an average of 10% from 1993-2000, slightly lower than the 11% increase in value, for a total increase of 118%. The one exception is 1993-1994, which experienced a decrease in weight due to the unusually high weight of goods by rail in 1993. This modification in the annual trend is likely the result of several potential weaknesses in the model (explained in section 3). Despite the higher value for 1993 from imports, the weight of exports was unusually low in 1993, offsetting the potential trend. Unlike the value of U.S. exports to Mexico, which actually decreased from 2001 to 2003, the weight of exports increased steadily over this time period. Seventy-four percent of good by weight were exported by truck in 2003, which was consistent with previous years.

Figure 3.2.2 Weight of U.S. Imports from Mexico (kg)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	13,387,8	13,816,9	17,405,1	19,295,3	21,253,0	22,926,4	25,729,0	27,323,6	28,050,9	29,029,0	29,146,1
Truck	9,234,25	10,612,6	13,528,4	14,481,7	16,157,1	17,496,1	19,667,2	20,687,9	20,429,4	21,213,5	21,692,5
Rail	4,153,57	3,204,20	3,876,68	4,813,54	5,095,91	5,430,28	6,061,75	6,635,67	7,621,44	7,815,52	7,453,59

Texas, California and Michigan account for 60% of U.S. Imports from Mexico by weight, similar to the portion they capture of U.S. imports by value. The freight transport modes of these three states are very different. Less than 8% of California goods are shipped by rail, compared to 26% from Texas and 64% from Michigan. In total 74% of all U.S. Imports from Mexico by weight enter via truck, compared to 24% by rail (for the two modes considered). The top 10 importing U.S. states received 83% of all trade by weight in 2003

Table 3.2.3 2003 Weight of U.S. Imports from Mexico to Top 10 U.S. States (kg)

	Truck	%	Rail	%	Total	%
TX	6,736,909,363	31%	2,338,078,653	31%	9,074,988,016	31%
CA	4,536,820,646	21%	390,820,835	5%	4,927,641,481	17%
MI	1,264,728,676	6%	2,264,994,256	30%	3,529,722,932	12%
AZ	1,893,026,093	9%	161,463,159	2%	2,054,489,252	7%
IL	861,842,519	4%	966,184,307	13%	1,828,026,826	6%
OH	646,206,140	3%	39,944,066	1%	686,150,206	2%
GA	452,636,870	2%	110,868,907	1%	563,505,777	2%
PA	262,286,136	1%	263,250,869	4%	525,537,005	2%
MO	457,254,812	2%	53,071,996	1%	510,326,808	2%
NY	446,851,624	2%	35,007,397	0%	481,859,021	2%
Other	4,133,991,811	19%	829,908,840	11%	4,963,900,651	17%
Total	21,692,554,690	100%	7,453,593,285	100%	29,146,147,975	100%

Agriculture tops the list of commodities imported from Mexico to the United States by weight, accounting for 27% of total U.S. imports. This is in contrast to only 8% of imports by value. Manufactured goods and vehicles are also heavily imported, accounting for 18% and 14% respectively. Not surprisingly, the largest increase in Mexican products imported to the United States was for textiles, followed by plastics and vehicles. Minerals and wood increased only slightly from 1993 to 2003, by 6% and 12% respectively. The total average increase by weight was 127% for all commodities. This is comparable to the 131% increase of imports by value, when adjusted for inflation.

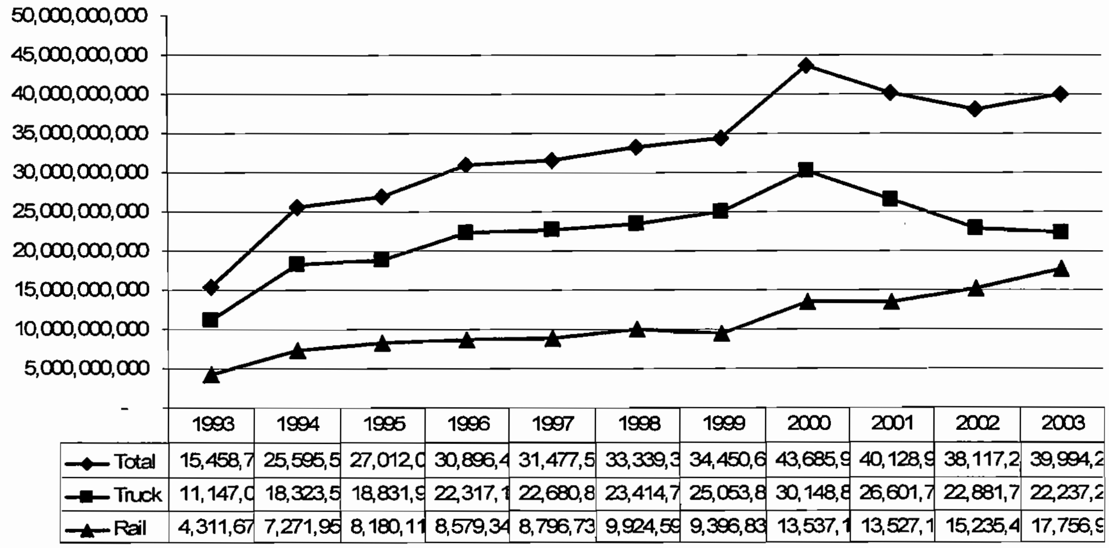
Table 3.2.4 Weight of U.S. Imports from Mexico by Sector in 1993 & 2003 (kg)

	1993	%	2003	%	% Change
Agriculture	3,180,123,196	25%	7,873,225,317	27%	248%
Manufactured goods	2,138,527,428	17%	5,195,610,847	18%	243%
Vehicles	1,255,160,648	10%	4,001,972,714	14%	319%
Metal	1,472,007,639	11%	3,012,184,499	10%	205%
Stone	830,119,653	6%	2,013,570,765	7%	243%
Other	931,871,716	7%	1,851,459,585	6%	199%
Minerals	1,403,017,962	11%	1,492,444,266	5%	106%
Chemicals	480,642,263	4%	1,108,926,324	4%	231%
Plastics	273,248,268	2%	989,011,735	3%	362%
Textiles	244,934,407	2%	924,193,826	3%	377%
Wood	607,645,995	5%	683,548,097	2%	112%
Total	12,817,299,176	100%	29,146,147,975	100%	227%

Weight of U.S. Exports to Mexico

The weight of exports increased by 158%, which is significantly more than the weight of imports, which increased by 118%. U.S. exports to Mexico by weight are heavily dominated by agricultural, particularly cereals and grain. As described below, these commodities continued to rise despite the economic downturn in 2001. As a result, the weight of U.S. exports to Mexico shows a surprising trend. Shipments by rail increased at nearly twice the rate of truck shipments, changing from 4.3 billion kg in 1993 to nearly 18 billion kg in 2003. While 86% of exports by value were shipped by truck in 2003, only 55% of exports by weight were shipped by truck in 2003. This is in contrast to 72% in 1993.

Figure 3.2.3 Weight of U.S. Exports to Mexico (kg)



The rather surprising modal shift to rail began in 2001 and continued through 2003. It can be explained by steady increases in the shipments of agricultural goods by rail while manufacturing goods, typically shipped by truck, decreased. Table 3.2.5 shows that between 2000 and 2003 the volume of U.S. agricultural exports doubled, with the second highest category, milling products, increasing by 454% (the value of goods increased by nearly 400%).

Figure 3.2.5 Weight of top 10 agricultural commodities (kg)

	2,000	2001	2,002	2,003	% Change
Cereals	3084730110	3707919158	4,697,796,305	5,834,460,811	89%
Milling prods	191328353.2	330629829.2	745,846,222	1,060,289,831	454%
Oil seeds etc.	548907696.6	630339914.3	861,075,539	854,052,581	56%
Prep animal feed	261992227.6	288482074.8	361,883,366	508,601,468	94%
Animal or veg fats	158796675.8	207563634.5	418,792,782	301,784,017	90%
Dairy prod	28635324.72	80069958.49	63,002,365	98,418,680	244%
Edible vegetables	41126068.14	50582496.04	59,923,118	64,386,039	57%
Beverages	25296032.56	37595174.4	38,240,722	58,955,301	133%
Sugars	122177611.9	88812731.97	19,856,974	39,131,015	-68%
Prep vegetables	8328783.498	5619665.202	6,597,068	15,632,144	88%
Other	22,650,334	25,679,317	33,768,694	27,034,061	19%
Total	4,493,971,218	5,453,295,955	7,306,785,156	8,862,747,950	97%

The distribution of U.S. exports to Mexico by weight contrasts sharply with exports by value. While agriculture accounts for only 8% of exports by value it is responsible for 30% of shipments by weight. Minerals, the second highest category of U.S. exports by weight at 12% of total shipments, account for only 1% of U.S. exports by value. Manufactured goods and vehicles are cumulatively responsible for 14% of weight in contrast to 63% of goods shipped by value.

Table 3.2.8 Weight of U.S. Exports to Mexico by Sector in 1993 & 2003 (kg)

	1993	%	2003	%	% Change
Agriculture	5,593,841,825	29%	15,702,068,773	32%	181%
Wood products	3,086,508,244	16%	5,404,013,621	11%	75%
Metal products	2,177,241,900	11%	5,141,272,658	10%	136%
Minerals	2,366,635,403	12%	5,072,695,888	10%	114%
Plastics	1,262,697,398	6%	4,459,632,109	9%	253%
Chemicals	1,687,836,248	9%	4,123,216,628	8%	144%
Manufactured goods	1,396,925,663	7%	3,820,143,415	8%	173%
Vehicles & parts	711,717,579	4%	2,444,055,069	5%	243%
Textiles	304,756,348	2%	1,405,033,116	3%	361%
Stone & ceramics	438,156,352	2%	1,142,102,182	2%	161%
Other	447,031,725	2%	499,117,495	1%	12%
Total	19,473,348,684	100%	49,213,350,953	100%	153%

The weight of U.S. exports to Mexico is given in tables 3.2.6 and 3.2.7. In a similar pattern to value, Texas and California are the largest exporters. While Michigan is the third largest exporter by value, it ships only 3% of goods by weight, illustrating the high value of vehicles on a value to weight basis. The majority of goods from U.S. border states are shipped by truck, while rail dominates shipping further from the border.

Table 3.2.6 2003 Weight of U.S. Exports to Mexico from Top 10 U.S. States (kg)

	truck	%	Rail	%	Total	%
TX	10,154,335,663	46%	5,823,987,847	33%	15,978,323,511	40%
CA	4,064,280,751	18%	632,497,494	4%	4,696,778,245	12%
IA	95,450,206	0%	1,745,529,335	10%	1,840,979,541	5%
NE	44,642,772	0%	1,445,696,596	8%	1,490,339,368	4%
AZ	992,052,712	4%	212,158,614	1%	1,204,211,326	3%
IL	569,410,806	3%	573,105,086	3%	1,142,515,892	3%
MI	638,917,377	3%	407,818,197	2%	1,046,735,574	3%
PA	355,366,815	2%	582,620,170	3%	937,986,985	2%
KS	111,280,061	1%	723,720,237	4%	835,000,298	2%
LA	388,951,477	2%	418,450,728	2%	807,402,205	2%
Other	4,822,542,954	22%	5,191,408,873	29%	10,013,951,826	25%
Total	22,237,231,594	100%	17,756,993,178	100%	39,994,224,772	100%

Mexican border states and the heavily populated regions of Mexico City and Jalisco (Guadalajara) account for the vast majority of shipments (87% in total) to Mexico. Roughly a quarter of all goods by weight are shipped to the Mexico City region, followed by Chihuahua (19%) and Baja California (14%). While roughly half the weight of goods is shipped to Mexico City by rail, about 80% of goods shipped to border states arrive by truck.

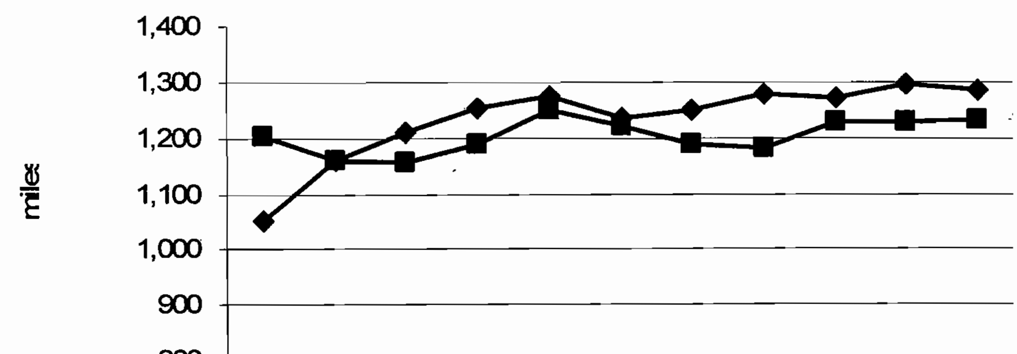
Table 3.2.7 2003 Weight of U.S. Exports to Mexico to Top 10 Mexican States (kg)

	Truck	%	Rail	%	Total	%
MX	2,710,503,054	12%	2,911,031,836	16%	5,621,534,890	14%
CH	4,295,372,351	19%	1,229,882,506	7%	5,525,254,857	14%
DF	2,713,189,206	12%	2,471,083,536	14%	5,184,272,742	13%
NL	1,939,937,601	9%	2,702,072,518	15%	4,642,010,119	12%
BC	3,142,691,508	14%	606,397,425	3%	3,749,088,933	9%
JA	753,047,840	3%	1,949,279,842	11%	2,702,327,682	7%
CO	1,486,311,340	7%	1,077,796,682	6%	2,564,108,022	6%
TM	1,887,223,741	8%	124,515,658	1%	2,011,739,399	5%
SO	943,325,121	4%	533,754,245	3%	1,477,079,365	4%
GT	503,199,819	2%	877,036,789	5%	1,380,236,608	3%
Other	1,862,430,013	8%	3,274,142,142	18%	5,136,572,155	13%
Total	22,237,231,594	100%	17,756,993,178	100%	39,994,224,772	100%

3.3 Miles

The average distance U.S. imports from Mexico are shipped grew from 1,050 miles in 1993 to 1,287 in 2003. This indicates that NAFTA may have played a role in encouraging manufacturing south of the free trade zones long established along the U.S. Mexico border. It also increases the total amount of air pollution from transport vehicles. The greatest increase occurred in the early NAFTA years, leveling from 1997 onwards. U.S. exports to Mexico did not experience such growth, but rather fluctuated around 1,200 miles throughout this period.

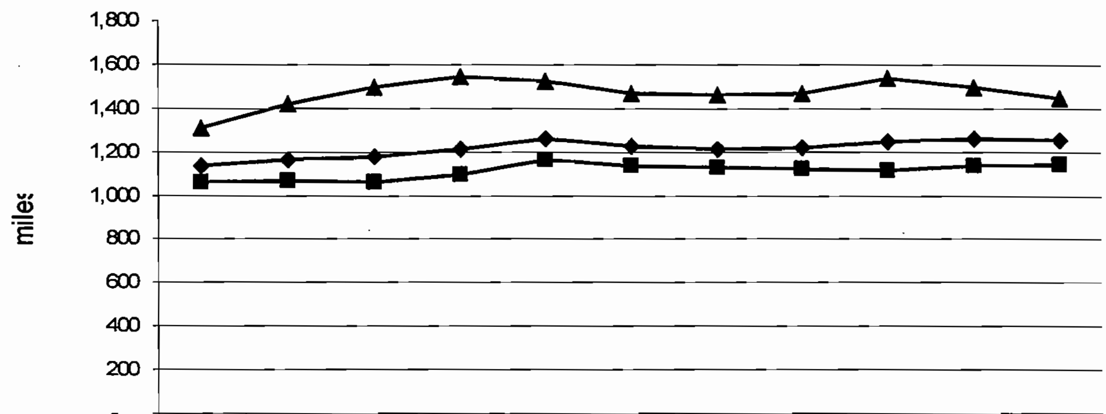
Table 3.3.1 Average Miles of U.S. Imports from Mexico, 1993-2003



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Imports	1,050	1,158	1,209	1,252	1,274	1,233	1,250	1,278	1,272	1,297	1,287
Exports	1,203	1,160	1,157	1,188	1,249	1,222	1,187	1,180	1,227	1,227	1,231

Goods shipped by rail travel roughly 25%, or roughly 300 miles, further than goods shipped by truck. The overall long-term trend shows an increase in the distance goods are shipped. The average distance of goods shipped by truck increased by 8% while the average distance of goods shipped by rail increased by 10%.

Table 3.3.2 Average Miles of Total Trade by Transport Mode, 1993-2003

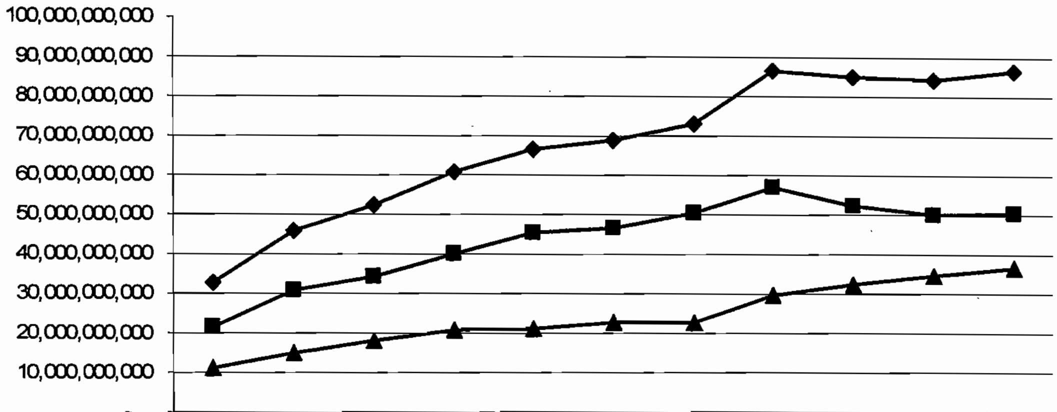


	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	1,132	1,160	1,177	1,212	1,259	1,226	1,214	1,218	1,245	1,257	1,254
Truck	1,060	1,066	1,059	1,091	1,165	1,135	1,128	1,120	1,115	1,133	1,143
Rail	1,306	1,419	1,494	1,547	1,520	1,470	1,462	1,465	1,535	1,495	1,448

3.4 Ton-miles

Ton-miles of U.S. trade with Mexico grew from 32 billion in 1993 to nearly 87 billion in 2003 for an annual average increase of 11% (166% in total). The dramatic increase in ton-miles from 1993 to 2000 (18% annually) was followed by three stagnant years. This combination of no growth in ton-miles and the modal shift to rail is significant in terms of air pollutants, which all decreased over this time period. While ton-miles from trucking declined during the poor economic years of 2001-2003, ton-miles from rail continued to rise. Trucking accounted for 69% of all ton-miles in 1999 and 58% in 2003.

Figure 3.4.1 Ton-miles of U.S. trade with Mexico by Truck and Rail



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	32,656,	45,705,	52,294,	60,851,	66,375,	69,004,	73,060,	86,459,	84,892,	84,410,	86,714,
Truck	21,604,	30,841,	34,276,	40,134,	45,258,	46,432,	50,460,	56,913,	52,422,	49,953,	50,202,
Rail	11,052,	14,864,	18,018,	20,717,	21,116,	22,571,	22,599,	29,545,	32,469,	34,456,	36,511,

While Michigan is the third largest state in terms of value and weight, it surpasses California in ton-miles. The majority of these ton-miles, however, are by rail, which is a far less polluting form of transport than truck (see air emissions below). Texas, Michigan and California accounted for 41% of ton-miles (compared to 64% by value and 57% by weight). The top ten states accounted for less than two-thirds of all ton-miles, compared to 83% by value and 77% by weight. Much of the long-distance hauling was done by rail, while the majority of ton-miles from border states was by truck.

Table 3.4.1 Ton-miles of U.S. trade with Mexico by U.S. State

	Truck	%	Rail	%	Total	%
TX	11,499,553,284	23%	6356914215	17%	17,856,467,499	21%
MI	4,069,000,121	8%	5720988559	16%	9,789,988,680	11%
CA	6,857,443,785	14%	1281864293	4%	8,139,308,078	9%
IL	2,388,083,986	5%	2578965536	7%	4,967,049,522	6%
PA	1,449,557,002	3%	2053963083	6%	3,503,520,085	4%
IA	329,469,432	1%	2971892334	8%	3,301,361,765	4%
OH	2,361,382,271	5%	600024864.4	2%	2,961,407,135	3%
NY	1,963,448,626	4%	509249197.6	1%	2,472,697,824	3%
NE	98,917,997	0%	2311727122	6%	2,410,645,119	3%
GA	1,263,122,370	3%	836917636.1	2%	2,100,040,006	2%
Other	17,916,183,572	36%	11,288,365,856	31%	29,204,549,428	34%
Total	50,196,162,446	100%	36,510,872,696	100%	86,707,035,141	100%

Agricultural goods accounted for 27% of total ton-miles, although this sector was responsible for only 8% of the value of U.S. – Mexico trade in 2003. There were over 23 billion ton-miles of agricultural good shipped between the Mexico and the United states in 2003, which is equivalent to roughly 230 ton-miles per Mexican resident and 75 ton-miles per U.S. resident. Manufactured goods and vehicles accounted for 25% of total ton-miles and experienced high growth. Textiles accounted for the smallest number of ton-miles but experienced a nearly five-fold increase in ton-miles over 1993.

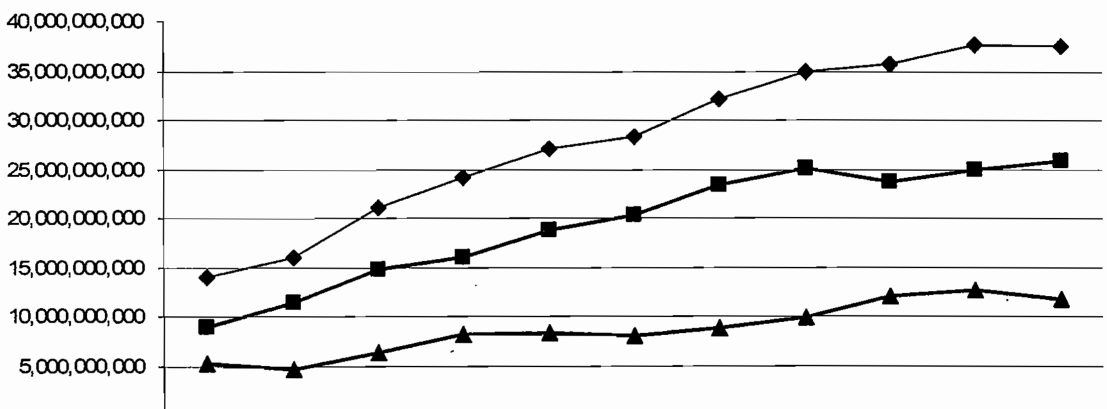
Table 3.4.2 Ton-miles of U.S. Trade with Mexico by Sector, 1993 & 2003

	1993	%	2003	%	% Change
Agriculture	8,176,868,525	25%	23,039,566,366	27%	182%
Manufactured goods	3,796,047,652	12%	11,563,676,491	13%	205%
Vehicles & parts	2,693,196,802	8%	9,985,050,695	12%	271%
Metal products	3,677,780,207	11%	8,822,905,950	10%	140%
Minerals	3,678,299,544	11%	6,647,670,614	8%	81%
Wood products	3,675,458,182	11%	6,243,876,707	7%	70%
Plastics	1,563,772,099	5%	5,961,098,887	7%	281%
Chemicals	2,259,774,921	7%	5,618,372,985	6%	149%
Stone & ceramics	1,348,979,406	4%	3,273,442,424	4%	143%
Other	1,427,514,266	4%	2,890,013,984	3%	102%
Textiles	547,289,274	2%	2,668,537,302	3%	388%
Total	32,844,980,878	100%	86,714,212,403	100%	164%

Ton-miles of U.S. Imports from Mexico

Ton-miles of U.S. imports from Mexico increased fairly constantly over the 11 years studied. The 37 billion ton-miles of U.S. imports from Mexico represent an 11% annual increase, or 167% increase overall. The decline in ton-miles in 2001 was accompanied by an increase in ton-miles from rail. Ton-miles from trucking also quickly recovered in 2002 and surpassed 2000 levels in 2003.

Figure 3.4.2 Ton-miles of U.S. Imports from Mexico



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	14,061,1	16,005,1	21,035,0	24,148,9	27,068,7	28,278,6	32,172,7	34,927,1	35,667,3	37,658,8	37,500,8
Truck	8,893,44	11,384,4	14,714,2	16,060,9	18,784,3	20,240,0	23,348,6	25,018,7	23,654,0	24,974,0	25,804,7
Rail	5,167,73	4,620,64	6,320,78	8,088,03	8,284,40	8,038,58	8,824,09	9,908,41	12,013,2	12,684,8	11,696,0

The U.S. state of Michigan receives the largest share of ton-miles, at 7.6 billion in 2003. Sixty-four percent of the ton-miles were by rail, however, making the impact on air emissions far less dramatic. Despite their proximity to Mexico, Texas and California also received sizable freight activity with 17% and 11% of ton-miles, respectively.

Table 3.4.3 2003 Ton-miles of U.S. Imports from Mexico to Top 10 U.S. States

	Truck	%	Rail	%	Total	%
MI	2,768,242,830	11%	4,859,878,771	42%	7,628,121,601	20%
TX	4,690,969,006	18%	1,776,403,090	15%	6,467,372,096	17%
CA	3,442,260,771	13%	629,156,026	5%	4,071,416,797	11%
IL	1,449,140,070	6%	1,599,047,257	14%	3,048,187,328	8%
OH	1,323,826,974	5%	78,682,564	1%	1,402,509,539	4%
PA	616,469,878	2%	663,040,504	6%	1,279,510,382	3%
NY	1,177,188,562	5%	88,931,727	1%	1,266,120,289	3%
AZ	949,692,765	4%	72,333,314	1%	1,022,026,079	3%
GA	773,994,869	3%	190,896,537	2%	964,891,406	3%
NC	901,198,816	3%	58,256,855	0%	959,455,670	3%
Other	7,711,786,514	30%	1,679,463,749	14%	9,391,250,264	25%
Total	25,804,771,055	100%	11,696,090,394	100%	37,500,861,449	100%

The top sectors of manufactured goods, vehicles and agriculture have all captured an increasingly larger share of ton-miles, growing from 52% of ton-miles in 1993 to 61% of ton-miles in 2003. Ton-miles from heavy manufacturing (including manufactured goods and vehicles) accounted for 41% of U.S. imports from Mexico overall in 2003. Ton-miles from textiles and plastics increased the most at 424% and 399% growth, respectively. This is in contrast to minerals and wood, which grew by only 20% and 43%, respectively. The total average increase in ton-miles from 1993 to 2003 was 180%.

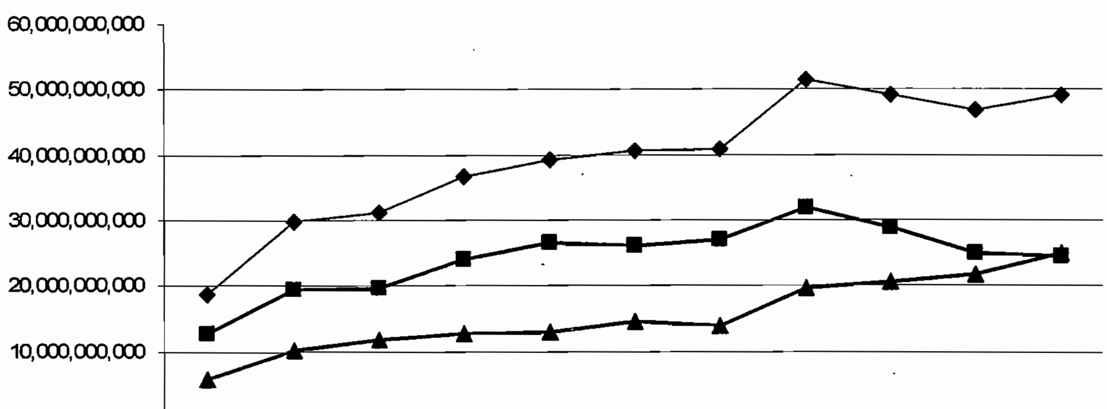
Table 3.4.4 Ton-miles of U.S. Imports from Mexico by Sector in 1993 & 2003

	1993	%	2003	%	% Change
Manufactured goods	2,399,121,989	18%	7,743,533,076	21%	223%
Vehicles & parts	1,981,479,223	15%	7,540,995,626	20%	281%
Agriculture	2,583,026,700	19%	7,337,497,593	20%	184%
Metal products	1,500,538,307	11%	3,681,633,292	10%	145%
Other	980,482,541	7%	2,390,896,489	6%	144%
Stone & ceramics	910,823,054	7%	2,131,340,243	6%	134%
Minerals	1,311,664,141	10%	1,574,974,726	4%	20%
Plastics	301,074,701	2%	1,501,466,778	4%	399%
Chemicals	571,938,673	4%	1,495,156,357	4%	161%
Textiles	242,532,926	2%	1,263,504,185	3%	421%
Wood	588,949,938	4%	839,863,086	2%	43%
Total	13,371,632,194	100%	37,500,861,449	100%	180%

Ton-miles of U.S. Exports to Mexico

Ton-miles from U.S. exports to Mexico grew from 18.6 billion in 1993 to 51 billion in 2000 (an increase of 177%) but decreased by 2002 to 46.8 billion. The surprising finding is that ton-miles by rail grew even more dramatically in 2000-2003, led by exports in agricultural goods from Midwestern states. Ton-miles of rail exports actually surpassed ton-miles from trucks in 2003. This modal shift has less of an effect on air emissions than may be assumed, since increases in rail ton-miles do not lead to dramatic increases in emissions overall due to the efficiency by which rail transports heavy goods long distances.

Figure 3.4.3 Ton-miles of U.S. Exports to Mexico (US$)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	18,595,3	29,700,3	31,259,8	36,702,4	39,306,8	40,725,3	40,887,9	51,531,9	49,225,0	46,751,9	49,213,3
Truck	12,710,7	19,456,8	19,561,8	24,073,4	26,474,2	26,192,2	27,112,0	31,894,8	28,768,3	24,979,8	24,397,8
Rail	5,884,60	10,243,4	11,698,0	12,628,9	12,832,5	14,533,0	13,775,8	19,637,1	20,456,6	21,772,1	24,815,4

Texas tops U.S. states, with freight activity with 23% of total ton-miles, 60% of which are by truck. Iowa and Nebraska were responsible for 12% and 9% of ton-miles, respectively due to the large volume of agricultural products, shipped almost entirely by rail, from those states. In terms of air emissions, trucking is clearly the primary concern. Texas, California, Michigan and Ohio all shipped over one billion ton-miles in 2003.

Table 3.4.5 2003 Ton-miles of U.S. Exports to Mexico from Top 10 U.S. States

	Truck	%	Rail	%	Total	%
TX	6,808,584,278	28%	4,580,511,125	18%	11,389,095,403	23%
CA	3,415,183,014	14%	652,708,267	3%	4,067,891,281	8%
IA	159,168,456	1%	2,967,150,285	12%	3,126,318,741	6%
NE	70,097,598	0%	2,306,116,270	9%	2,376,213,868	5%
PA	833,087,124	3%	1,390,922,579	6%	2,224,009,703	5%
MI	1,300,757,291	5%	861,109,788	3%	2,161,867,079	4%
IL	938,943,915	4%	979,918,279	4%	1,918,862,194	4%
OH	1,037,555,297	4%	521,342,300	2%	1,558,897,597	3%
KS	165,335,125	1%	1,052,931,780	4%	1,218,266,905	2%
NY	786,260,064	3%	420,317,471	2%	1,206,577,535	2%
Other	8,882,902,122	36%	9,082,448,525	37%	17,965,350,648	37%
Total	24,397,874,284	100%	24,815,476,669	100%	49,213,350,953	100%

Mexico City and its surroundings received more than one-third of all U.S. – Mexico ton-miles. This is a factor of both the volume of goods shipped to those states and the distance. Roughly half of goods shipped to Mexico City arrive by truck with the other half arriving by rail. Border states receive a far larger portion of shipments by truck while non-border states (with the exception of Mexico City) received roughly 60% of shipments by rail.

Table 3.4.6 2003 Ton-miles of U.S. Exports to Mexico to Top 10 Mexican States

	1993	%	2003	%	% Change
Agriculture	5,593,841,825	29%	15,702,068,773	32%	181%
Wood products	3,086,508,244	16%	5,404,013,621	11%	75%
Metal products	2,177,241,900	11%	5,141,272,658	10%	136%
Minerals	2,366,635,403	12%	5,072,695,888	10%	114%
Plastics	1,262,697,398	6%	4,459,632,109	9%	253%
Chemicals	1,687,836,248	9%	4,123,216,628	8%	144%
Manufactured goods	1,396,925,663	7%	3,820,143,415	8%	173%
Vehicles & parts	711,717,579	4%	2,444,055,069	5%	243%
Textiles	304,756,348	2%	1,405,033,116	3%	361%
Stone & ceramics	438,156,352	2%	1,142,102,182	2%	161%
Other	447,031,725	2%	499,117,495	1%	12%
Total	19,473,348,684	100%	49,213,350,953	100%	153%

As stated previously, agricultural products dominate total ton-miles at 15.7 billion in 2003, or 32% of total ton-miles. The vast majority of these agricultural ton-miles, however, are by rail (77%, or 12.6 billion ton-miles in 2003). Ton-miles from agriculture increased from 29% of the total in 1993 to 32% of total ton-miles in 2003. Wood products accounted for 11% of ton-miles in 2003, despite only accounting for 4% of total exports by value. Metal products, minerals, plastics, chemicals and manufactured good all accounted for roughly 10% of ton-miles each. Vehicles and parts, which accounted for 12% of exports by value in 2003 only accounted for 5% of ton-miles. Overall, ton-miles of exports increased by 150% over 1993 values.

Table 3.4.7 Ton-miles of U.S. Exports to Mexico by Sector in 1993 & 2003

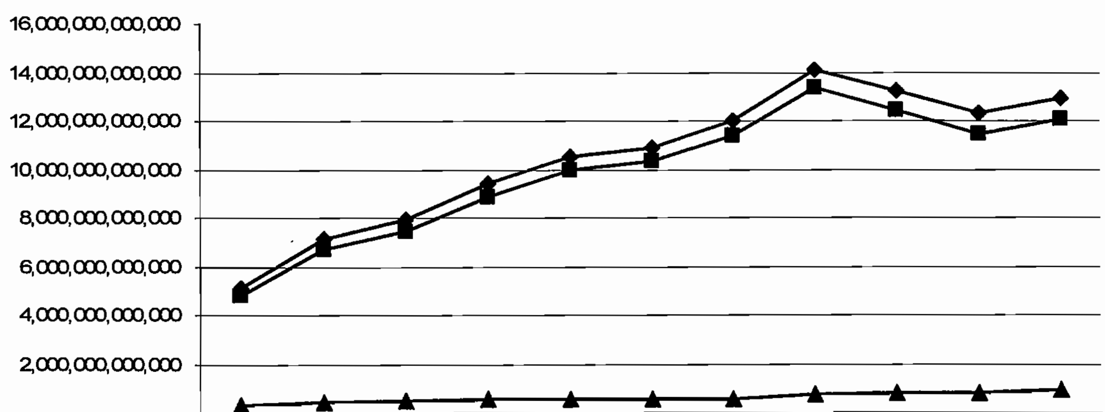
	1993	%	2003	%	% Change
Agriculture	4,375,981,853	27%	11,832,359,131	30%	170%
Minerals	1,956,562,166	12%	4,627,528,081	12%	137%
Metal	2,028,408,813	13%	4,378,642,990	11%	116%
Plastic	1,073,531,517	7%	4,031,030,342	10%	275%
Wood	2,498,973,310	16%	3,975,328,111	10%	59%
Manufactured goods	1,319,371,984	8%	3,791,950,635	9%	187%
Chemicals	1,212,797,926	8%	2,999,308,635	7%	147%
Vehicles	565,825,235	4%	1,877,548,397	5%	232%
Textiles	246,560,539	2%	1,135,798,004	3%	361%
Stone	390,467,331	2%	894,304,373	2%	129%
Other	407,832,268	3%	450,426,073	1%	10%
Total	16,076,312,942	100%	39,994,224,772	100%	149%

3.5 Carbon Dioxide

Total emissions of carbon dioxide (CO_2) from U.S. – Mexico freight transport increased from 5 million metric tons ($MtCO_2$) in 1993 to 13 million metric tons in 2003, a change of 150%. This equates to 3.7% of U.S. emissions from freight, 0.7% of all CO_2 emissions from U.S. transportation, 0.23% of U.S. CO_2 emissions, and 0.06% of global CO_2 emissions[10].

Emissions from rail freight transport are dramatically lower than CO_2 emissions from trucking. As stated in the methods section, the conversion factor from ton-miles to CO_2 simply considers all emissions of CO_2 for each mode divided by all ton-miles (as reported by government inventories). Using this methodology, shipping a ton of goods by train in 2003 resulted in 25 grams of CO_2, while shipping a ton of good by freight resulted in 240 tons of CO_2. Considering all truck and train industry activities (including truck idling, empty loads, routing inefficiencies, etc.), trains are nearly 10 times more efficient in shipping a ton of goods. As a result, this study concludes that in 2003 trucking accounted for 93% of all CO_2 emissions from U.S. Mexico trade.

Figure 3.5.1 Emissions of CO_2 from U.S. – Mexico Trade, 1993-2003 (grams)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	5,119,16	7,150,35	7,953,17	9,411,80	10,519,4	10,895,9	11,985,3	14,108,3	13,216,1	12,288,6	12,939,7
Truck	4,788,40	6,722,63	7,461,41	8,863,09	9,957,71	10,312,9	11,406,8	13,374,4	12,416,0	11,475,4	12,038,3
Rail	330,757,	427,719,	491,759,	548,714,	561,701,	582,997,	578,522,	733,861,	800,072,	813,150,	901,407,

[10] Based on data from US EPA (2005), "Inventory of Greenhouse Gases", Chapter 5.

Manufactured goods and agriculture accounted for the largest sectors contributing to carbon dioxide emissions, each at 19% of total emissions. The growth in emissions between these two sectors differs dramatically with manufactured goods showing a 255% increase over 1993 levels, while agriculture increased by only 81%. This is partly because agricultural goods have been increasingly shipped by rail, particularly grains from the Midwestern United States, while manufactured goods are generally shipped by truck. Carbon dioxide emissions from the vehicles sector and the textiles sector increased even more dramatically, at 297% and 519%, respectively.

Table 3.5.1 Carbon Dioxide from U.S. – Mexico Trade by Sector (grams)

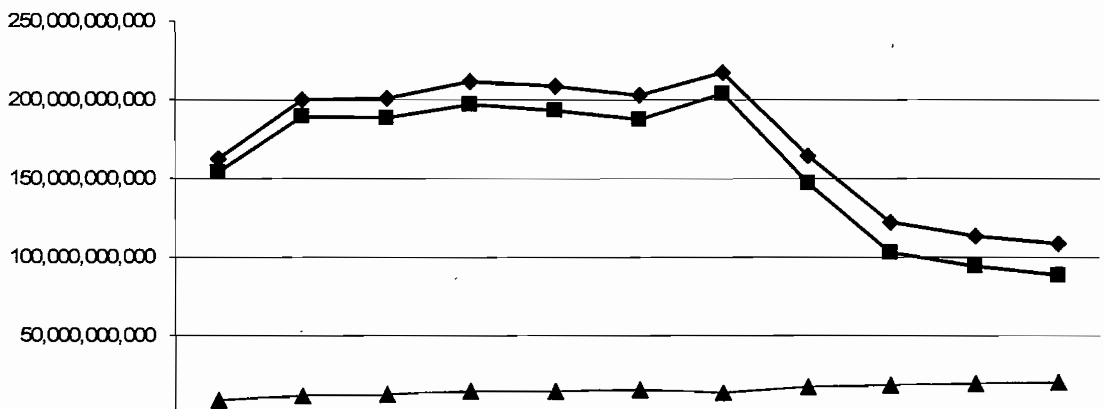
	1993	%	2003	%	% Change
Manufactured goods	706,458,728,437	14%	2,510,988,951,852	19%	255%
Agriculture	1,327,103,948,831	26%	2,402,324,856,667	19%	81%
Metal products	624,754,193,174	12%	1,396,906,255,722	11%	124%
Vehicles & parts	289,110,738,803	6%	1,148,490,265,789	9%	297%
Plastics	321,500,016,940	6%	1,094,964,045,470	8%	241%
Chemicals	329,888,902,110	6%	898,631,524,003	7%	172%
Stone & ceramic	284,221,810,465	6%	744,477,748,081	6%	162%
Minerals	363,470,605,750	7%	729,579,752,944	6%	101%
Wood products	542,217,971,941	11%	711,212,698,607	5%	31%
Other	247,421,916,378	5%	677,772,657,635	5%	174%
Textiles	100,877,680,045	2%	624,367,396,613	5%	519%
Total	5,137,026,512,873	100%	12,939,716,153,384	100%	152%

3.6 Criteria Pollutants

Carbon Monoxide

Despite an 18% annual growth in ton-miles from 1993 to 2000, the level of carbon monoxide emitted from freight transport vehicles remained roughly stable due to improvements in truck vehicle and engine technologies. CO emissions subsequently began to fall precipitously in 2000, one year before ton-miles began to decline. While the actual fleet of U.S. – Mexico trucks may have different technologies than the U.S. trucks used as the basis of this study, a general downward trend in CO emissions can be expected as older vehicles are replaced with newer ones on both sides of the border. In total CO emissions declined from 160 Gg (Gigagrams) at their peak in 1999 to 110 Gg in 2003.

Figure 3.6.1 CO Emissions from U.S. – Mexico Trade, 1993-2003 (grams)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	162,652,	200,424,	201,288,	211,333,	208,217,	202,755,	217,133,	164,202,	121,678,	113,093,	109,101,
Truck	154,094,	189,347,	188,537,	197,085,	193,613,	187,588,	203,459,	146,849,	103,260,	93,977,0	88,728,4
Rail	8,557,66	11,077,1	12,751,3	14,247,6	14,604,2	15,167,2	13,674,1	17,352,7	18,417,9	19,116,5	20,372,7

In contrast to CO_2, agriculture was responsible for more CO emissions than manufactured goods (21% compared to 17%). This is because CO emissions from rail do not match the 10:1 advantage rail has with CO_2 emissions from trucks. While agriculture was responsible for the largest portion of CO, it was also one of the sectors that experienced the largest declines in freight emissions (declining by 45%). Despite the overall downward trend in CO emissions, freight emissions from the vehicles and textiles sectors grew over this time period (by 18 and 44%, respectively). Thus, increases in ton-miles shipped by truck outweighed the efficiencies in truck technologies. The vehicles sector grew from the 9th largest emitter (out of 11) of CO in 1993 to the 4th in 2003.

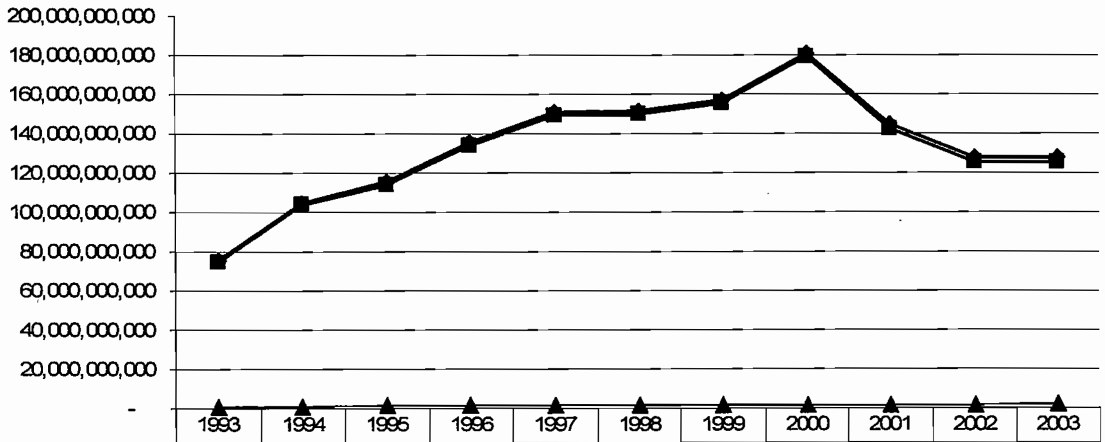
Table 3.6.1 CO Emissions from U.S. – Mexico Trade by Sector (grams)

	1993	%	2003	%	% Change
Agriculture	42,213,172,604	26%	23,164,497,753	21%	-45%
Manufactured goods	22,605,911,079	14%	18,965,094,891	17%	-16%
Metal products	19,918,657,898	12%	11,552,357,479	11%	-42%
Vehicles & parts	9,010,422,025	6%	10,642,786,111	10%	18%
Plastics	10,320,683,255	6%	8,655,112,421	8%	-16%
Chemicals	10,446,298,667	6%	7,407,579,854	7%	-29%
Minerals	11,253,511,577	7%	6,888,544,947	6%	-39%
Wood products	17,172,947,739	11%	6,616,018,147	6%	-61%
Stone & ceramic	9,132,226,496	6%	5,557,929,090	5%	-39%
Other	7,896,255,898	5%	5,022,160,235	5%	-36%
Textiles	3,225,555,100	2%	4,629,054,648	4%	44%
Total	163,195,642,338	100%	109,101,135,575	100%	-33%

Nitrogen Oxides

Nitrogen oxide (NO_X) emissions more than tripled between 1993 and 2000, but declined by 30% by 2002. Overall, NO_X emissions increased by 70%, rising from 75 Gg in 1993 to 127 Gg in 2003. Nearly all NO_X emissions were from trucks. The leveling of emissions between 2002 and 2003 suggests that NO_X emissions have since risen with the recovery of the economy and an increase in ton-miles. Thus, the overall trend is that technologies in trucks have not been able to keep pace with the steady rise of trade between the two countries. This will likely change, however, as new emissions standards implemented by the Bush administration will require dramatic reductions in new vehicle emissions by 2007.

Figure 3.6.2 NOx Emissions from U.S. – Mexico Trade, 1993-2003 (grams)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	75,480,8	104,549,	115,012,	135,202,	150,393,	151,178,	156,896,	181,071,	144,276,	127,331,	127,453,
Truck	74,661,8	103,496,	113,810,	133,872,	149,042,	149,884,	155,424,	179,351,	142,448,	125,422,	125,427,
Rail	819,011,	1,053,09	1,202,03	1,330,41	1,351,12	1,293,81	1,472,60	1,719,98	1,827,57	1,909,50	2,025,89

The manufacturing sectors (manufactured goods, vehicles, textiles, and plastics) experienced the highest growth. While NO_X emission from the manufactured goods sector increased by 141%, emission from agricultural freight increased by only 12%. As a result, in 2003, manufactured goods were responsible for nearly 4 Gg more NO_X than the agriculture industry, while in 1993 agriculture was responsible for nearly 9 Gg more NO_X than manufactured goods. Manufactured goods account for the largest share of NO_X emissions. This is because the majority of these goods are traded by truck, which release 55 times more NO_X emissions on a ton-miles basis (see methods section above). One sector, the wood products sector, decreased in NO_X emissions from freight.

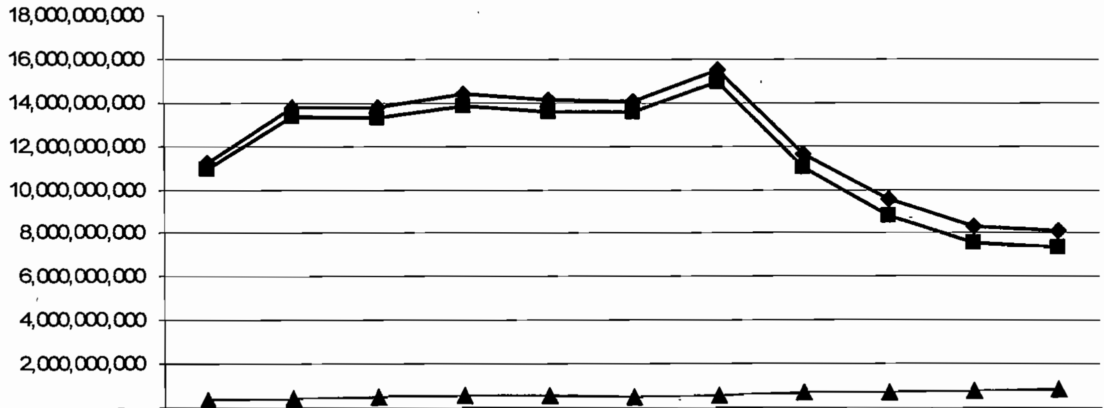
Table 3.6.2 NOx Emissions from U.S. – Mexico Trade by Sector (grams)

	1993	%	2003	%	% Change
Manufactured goods	10,747,096,417	14%	25,916,361,576	20%	141%
Agriculture	19,668,540,473	26%	22,101,403,431	17%	12%
Metal products	9,353,389,558	12%	13,880,254,258	11%	48%
Plastics	4,960,127,308	7%	11,094,742,468	9%	124%
Vehicles & parts	3,895,721,523	5%	10,797,664,908	8%	177%
Chemicals	4,790,942,831	6%	8,942,096,742	7%	87%
Stone & ceramic	4,401,920,131	6%	7,718,756,072	6%	75%
Other	3,720,232,480	5%	7,047,426,209	6%	89%
Minerals	4,745,267,513	6%	6,790,713,308	5%	43%
Wood products	7,882,013,817	10%	6,672,932,398	5%	-15%
Textiles	1,529,855,771	2%	6,490,718,603	5%	324%
Total	75,695,107,822	100%	127,453,069,973	100%	68%

Volatile Organic Compounds

Volatile organic compound (VOC) emissions rose slightly between 1993 and 1999, but declined dramatically thereafter, falling from 15.5 Gg in 1999 to 8 Gg in 2003. From 1993 to 2003 VOC emissions declined by 39%. As with other criteria pollutants, trucks made up the vast majority of emissions (90%). Improvements in vehicle technologies were roughly able to keep pace with the increase in ton-miles from 1993 to 2003, but decreased dramatically thereafter. It is unclear whether VOC emissions have risen since 2003, although it is very likely that they will not return to 1999 levels for many years to come.

Figure 3.6.3 VOC Emissions from U.S. – Mexico Trade, 1993-2003 (grams)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	11,227,6	13,790,5	13,769,8	14,392,9	14,121,0	14,052,1	15,505,0	11,644,7	9,533,45	8,295,32	8,104,67
Truck	10,907,6	13,378,4	13,298,7	13,870,6	13,589,7	13,537,7	14,933,9	10,975,8	8,822,73	7,522,93	7,307,98
Rail	320,043,	412,025,	471,041,	522,277,	531,339,	514,409,	571,009,	668,884,	710,724,	772,385,	796,698,

Agriculture and manufactured goods account for the largest shares of VOC emissions from freight transport, at 19% each; however, emissions from the agriculture sector have declined more rapidly (47%) than emissions from manufactured goods (3%). Agriculture also comprises a smaller percentage of VOC emissions overall than in 1993 when it accounted for more than a quarter of total emission. This decrease is due to slower growth in the sector compared to others, and the increasing importance of rail to ship heavier commodities such as grains. The average decrease in emissions was 28% from 1993 to 2003. Textiles and manufacturing were the only sectors to experience growth, rising by 68% and 23% respectively.

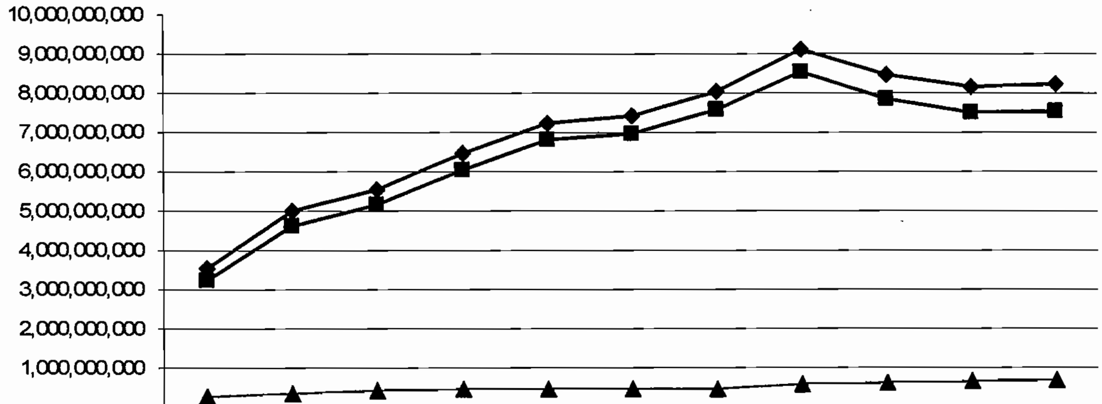
Table 3.6.3 VOC Emissions from U.S. – Mexico Trade by Sector (grams)

	1993	%	2003	%	% Change
Agriculture	2,920,900,818	26%	1,557,545,070	19%	-47%
Manufactured goods	1,582,429,302	14%	1,532,642,023	19%	-3%
Metal products	1,384,379,956	12%	870,839,470	11%	-37%
Vehicles & parts	597,326,192	5%	736,779,841	9%	23%
Plastics	727,087,771	6%	675,334,349	8%	-7%
Chemicals	716,234,551	6%	559,774,767	7%	-22%
Minerals	735,829,735	7%	470,360,930	6%	-36%
Wood products	1,178,024,502	10%	456,718,604	6%	-61%
Stone & ceramic	644,463,325	6%	453,228,695	6%	-30%
Other	549,841,476	5%	411,932,927	5%	-25%
Textiles	225,497,052	2%	379,522,125	5%	68%
Total	11,262,014,681	100%	8,104,678,800	100%	-28%

Particulate Matter

The estimate of particulate matter in this study largely follows changes in ton-miles since no reliable data could be found tracking changes in emissions factors of particulate matter for trucks over time. Fifteen grams per ton-mile for trucks was assumed to be the average emissions based on several studies (see methods section above), while 0.3 grams per miles was assumed for rail. Due to this difference in truck and rail emissions factors, particulate matter increased somewhat less than ton-miles, at 130% for PM10 compared to 166% for ton-miles.

Figure 3.6.3 PM10 Emissions from U.S. – Mexico Trade, 1993-2003 (grams)



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total	3,523,14	4,987,85	5,551,86	6,471,51	7,244,23	7,432,49	8,019,90	9,110,36	8,472,56	8,136,73	8,213,28
Truck	3,240,63	4,626,20	5,141,41	6,020,16	6,788,80	6,964,85	7,569,10	8,537,03	7,863,36	7,493,08	7,530,39
Rail	282,511,	361,651,	410,451,	451,351,	455,434,	467,645,	450,796,	573,329,	609,192,	643,654,	682,884,

Similar to other criteria pollutants, manufactured goods and agriculture account for the largest share of PM10 emissions. The share of agriculture decreased from 26% of emissions in 1993 to 19% of emissions in 2003. Textile, manufactured goods, vehicles and plastics increased the most overall, while wood products, agriculture and minerals increased the least.

Table 3.6.3 PM10 Emissions from U.S. – Mexico Trade by Sector (grams)

	1993	%	2003	%	% Change
Manufactured goods	481,610,949	14%	1,574,683,500	19%	227%
Agriculture	912,450,338	26%	1,550,059,983	19%	70%
Metal products	428,029,088	12%	884,708,048	11%	107%
Vehicles & parts	203,663,168	6%	737,302,700	9%	262%
Plastics	218,314,997	6%	690,008,358	8%	216%
Chemicals	228,069,187	6%	568,925,144	7%	149%
Minerals	258,408,262	7%	469,479,492	6%	82%
Stone & ceramic	192,745,880	5%	466,311,108	6%	142%
Wood products	374,917,595	11%	456,801,205	6%	22%
Other	169,252,997	5%	424,202,181	5%	151%
Textiles	68,871,557	2%	390,799,753	5%	467%
Total	3,536,334,017	100%	8,213,281,472	100%	132%

4. Discussion

The overall conclusions of this study are 1) carbon dioxide emissions from U.S. – Mexico trade have increased at roughly the same rate as the value of goods traded (although a little less in nominal terms and a little more in real terms), that is, by approximately 150% in 10 years; 2) Nitrogen oxide and particulate matter have increased significantly, by 70% and 130% respectively, and will likely continue to rise unless truck technologies improve; 3) carbon monoxide and volatile organic compounds have decreased over time, each by about 30%, but may rise if increases in trade flows outpace improved truck technologies; 4) trucking accounts for more than 90% of U.S. – Mexico overland freight emissions of CO_2, and the vast majority of criteria pollutant emissions; and 5) agriculture and manufactured goods account for the largest shares of freight air emissions, at roughly 20% each.

Trade is an essential part of any economy, bringing economic benefits and increased standards of living to an important share of residents. The North American Free Trade Agreement was established with these goals in mind; however, it is important to try to understand any negative environmental (as well as social) consequences of trade. Air pollution emissions from freight transport are frequently cited as an obvious side-effect of growing international trade, yet few studies have sought to model these consequences. As the first study to estimate greenhouse gas emission and criteria pollutants from U.S. - Mexico trade, this study seeks to quantify these impacts and demonstrate the potential of trade liberalization to influence air emissions from freight activity.

Generalizing these results beyond these two countries, however, would be problematic. The majority of U.S. – Mexico trade is shipped by trucks, a relatively highly polluting transport mode. The current study was chosen as essentially a worst-case example of the impact of liberalized trade on freight emissions. The U.S. Mexico border experiences some of the highest truck traffic in the world, second only to the U.S. – Canada border. This high volume of trade by truck makes expanding trade along this border a particularly high source of air pollutants.

Assessing the cumulative impact of globalization on freight emissions is a rather intractable problem. It stands to reason that since freight accounts for roughly 10% of all greenhouse gas emissions[11], increasing the distance goods are shipped could lead to significant increases in these gases since they are not readily captured by end-of-tailpipe technologies. However, the extent to which this occurs in relation to the total volume of goods traded is an open question. This will depend critically on the mode by which increasing trade occurs, changes in the transport of intermediary inputs to the production chain, changes in domestic shipping patterns to accommodate increased foreign trade, and the technology of future transport vehicles.

The dramatic increase in high value manufactured goods from China to the U.S., for example, is likely to result in far fewer emissions on a per value basis than U.S. – Mexico trade since these goods are shipped almost exclusively by ocean freight, which is on the order of 10 times more fuel efficient than trucks on a ton-mile basis[12]. On the other hand, if assembly plants can be located near parts manufacturing plants and sources of raw materials, then the distance final goods are shipped may become a trivial

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[11] OECD, 1997. "The Environmental Impacts of Trade".
[12] Interface Sustainability, 2005

consideration. In the case of China, the shipping of manufactured goods to the United States by ocean freight probably amounts to a very small quantity of emissions on a lifecycle basis. The opposite may be true for U.S. automakers currently shifting assembly facilities to Mexico. Finished vehicles are typically shipped by rail so locating auto assembly plants in Mexico will not lead to dramatic increases in emissions if new assembly plants are located near larger sources of parts and raw materials. For the most part, this does not appear to be the case. The large volume of shipments via truck from Michigan and other U.S. states to Mexico suggests that the U.S. auto industry is engaged in a massive long-distance exchange of intermediary parts and materials that results in very high and rapidly growing freight emissions.

The apparent inefficiencies of locating parts and assembly plants long-distances apart parallels what many see as unnecessary long-distance shipments of agricultural goods that could be produced locally. Indeed, this study shows that agriculture has been the top emitter of greenhouse gases and criteria pollutants from freight, at roughly 20% of total emissions. This trend is changing in part because lower than average growth in the value and volume of goods shipped, and because important agricultural commodities, such as grains, are increasingly shipped by rail. As a result, agriculture dropped from producing 26% of freight related CO_2 emissions on 1993 to 19% of CO_2 emissions in 2003.

Freight emissions seem to be on what one author has called "a collision course" with international efforts to reduce global warming[13]. The dramatic 150% increase in carbon dioxide from U.S. – Mexico freight transport in a single decade is in stark contrast to the goal of reducing emissions to 7% below 1990 levels under the Kyoto Protocol, to

[13] Simms, 2002.

which both the United States and Mexico are parties (although the United States has not ratified the treaty and Mexico, as a non-Annex 1 member, does not have binding emissions reductions targets). This study shows that that increasing long-distance trade can lead to large increases in greenhouse gas emissions from freight and that indeed it has in the case of U.S. – Mexico trade.

As a case study of the *potential* of international trade to influence freight emissions, the total amount of emissions from U.S. – Mexico trade is of less importance. In 2003, this study estimates that there were an estimated 52 billion ton-miles of cross-border trade by truck and 37 billion ton-miles of cross-border rail. This equates to roughly 4% of total U.S. ton-miles by truck, 2% of U.S. ton-miles by rail and an equivalent percentage of air emissions (totaling 13 Tg of CO_2, 110 Gg of CO, 127 Gg of NO_X, 8 Gg of VOCs and 8 Gg of PM10).

Perhaps the most significant value of this study is not the estimate of emissions, which is a specific use of the model developed, but the model itself. Published results of ton-miles between for U.S. – Mexico trade are not currently available, despite their importance as a metric of freight activity. The nine primary variables in the model (commodity type, year, transport mode, U.S. State, Mexico State, value, weight, miles, and ton-miles) could be analyzed many useful ways for different transportation and trade studies. The detailed summaries of value, weight and ton-miles by U.S. and Mexican states and by sector in this paper could provide important missing data for future trade and transportation studies.

5. Conclusion

Freight has been described as "the elephant in the corner" in climate change research. Globally, freight accounts for more than 10% of greenhouse gas emissions, yet it is highly understudied. Part of the problem is the political reluctance to address inefficiencies in the freight system because of the importance of trade in the international economy. Unreliable or non-existent freight transport data has also complicated efforts to understand the impact of freight emissions.

This study seeks to shed light on the potential impact of international freight on greenhouse gas and criteria pollutants. Despite improvements in truck and locomotive designs, carbon dioxide, nitrogen oxides and particulate matter have risen. While new U.S. standards for trucks (to be in effect in 2007) will likely play an important role in reducing criteria pollutants from trucks, addressing CO_2 emissions is quite another story since there are no feasible end-of-tailpipe solutions to reduce carbon dioxide emissions. There are, however, many ways in which policy decisions could limit the impact of freight on greenhouse gases including encouraging the use of alternative fuels or engine technologies, reducing idling time of trucks, mandating truck maintenance, limiting truck speeds, planning production systems to limit long-distance intra-industry transport, encouraging rail shipping, and encouraging local production and consumption. Generating the political will to make these more substantive changes to the way freight is shipped, however, will take efforts far beyond the scope of this paper.

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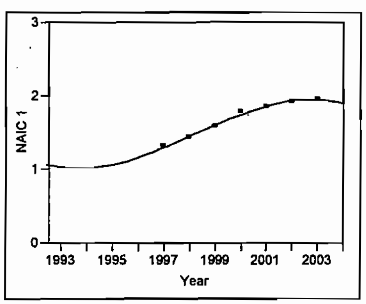
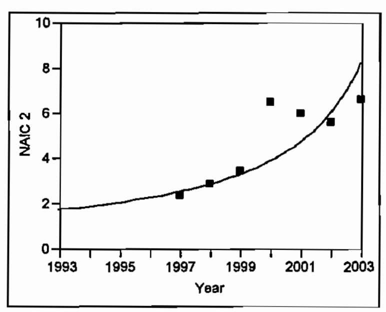
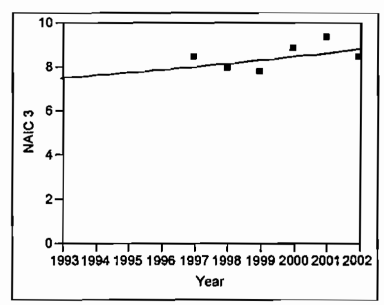
Appendix

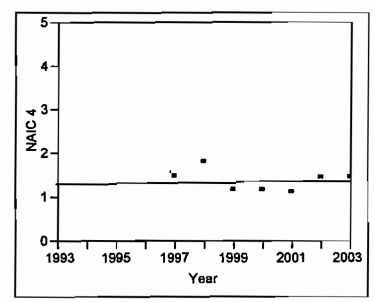
Value to weight ratios were used to estimate the weight of U.S. exports to Mexico from 1993 to 2003, and the weight of U.S. imports from Mexico from 1993 to 1996. Data for the value and weight of each NAIC commodity type were obtained from U.S. imports from Mexico for the years 1997 to 2003. For each year and each commodity the sum of all values is divided by the sum of all weights. In constructing the regression plots, each data point is “weighted” by the sum of the weight such that data points that represent a higher value of goods more strongly affect the regression lines. Regression analysis was used to predict the missing values for both truck and rail modes. There were sufficient shipments by truck to construct regression plots for all 98 NAIC commodities. Rail shipments for many commodity types were missing for these years. In these cases the value to weight ratios for trucks were used.

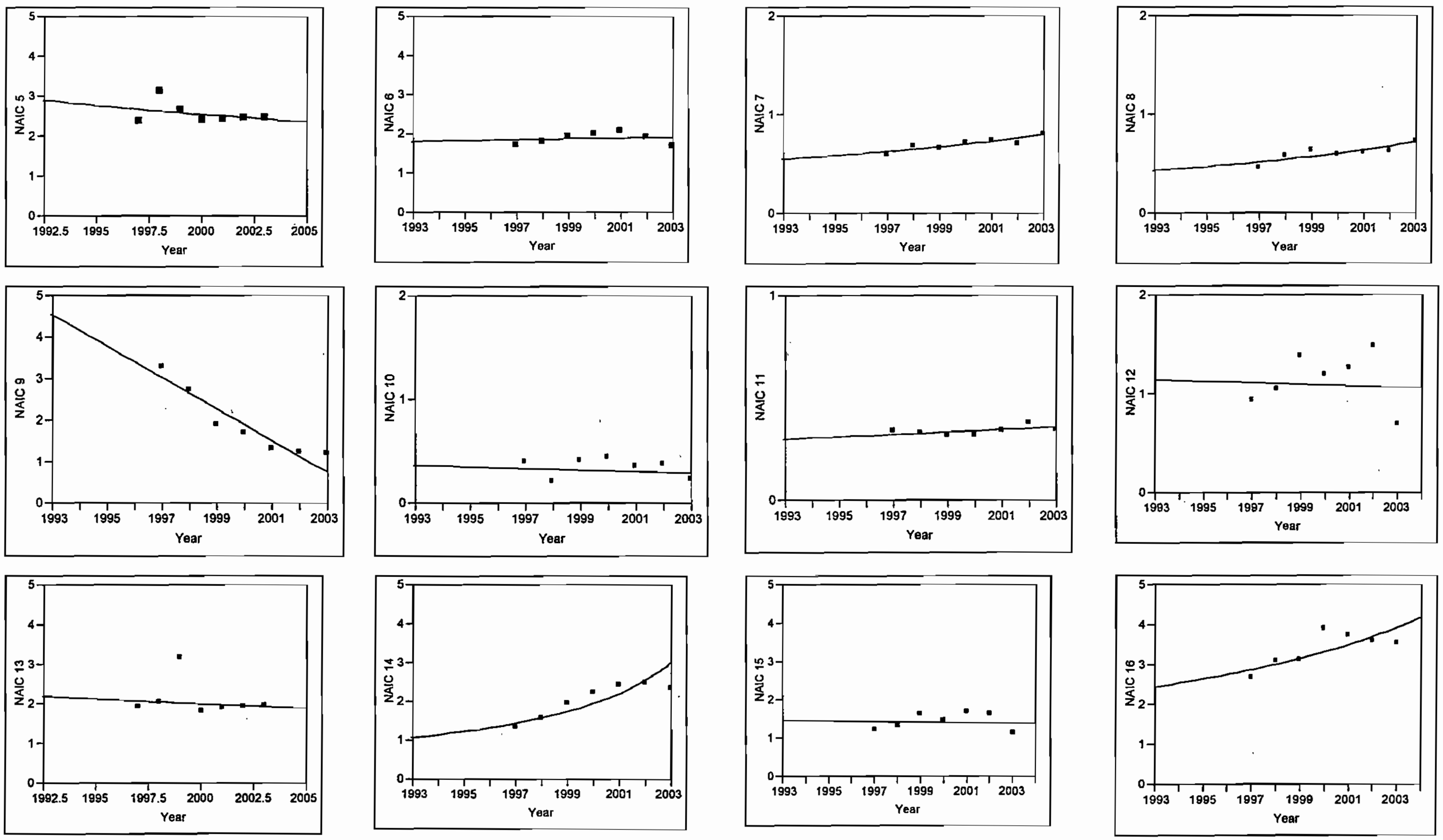
Regression Plots Used to Estimate Value to Weight Ratios for Trucks







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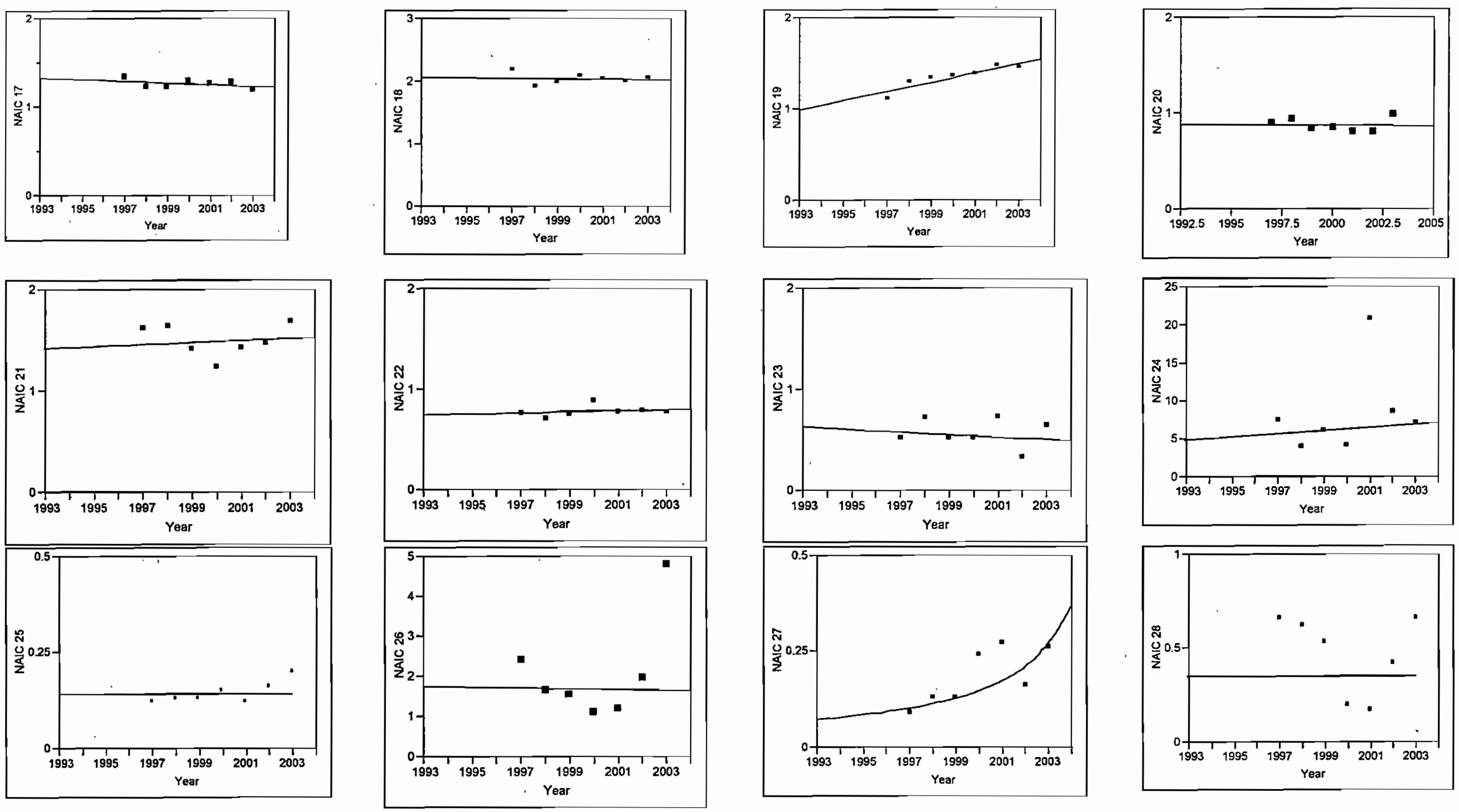
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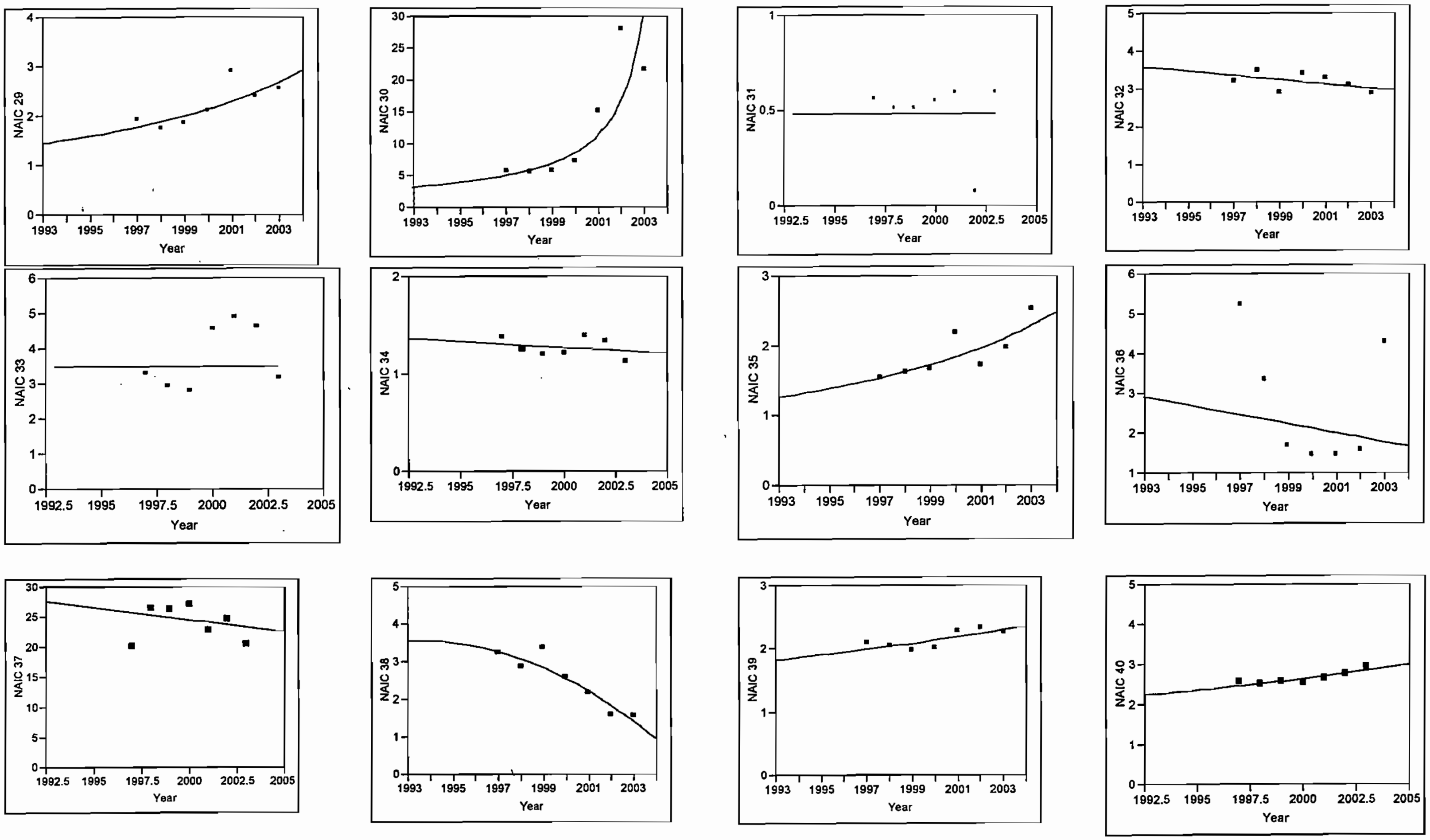
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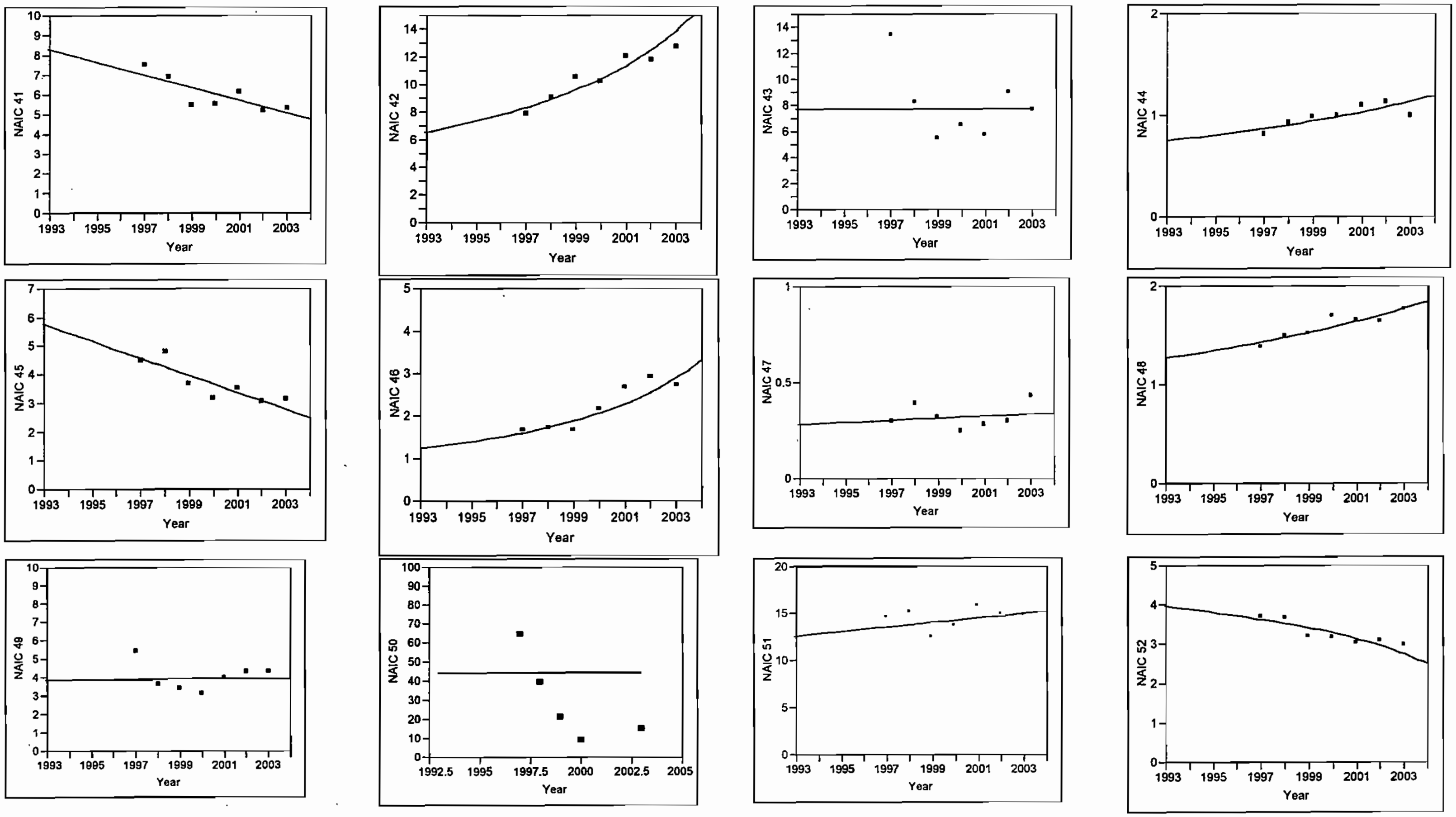
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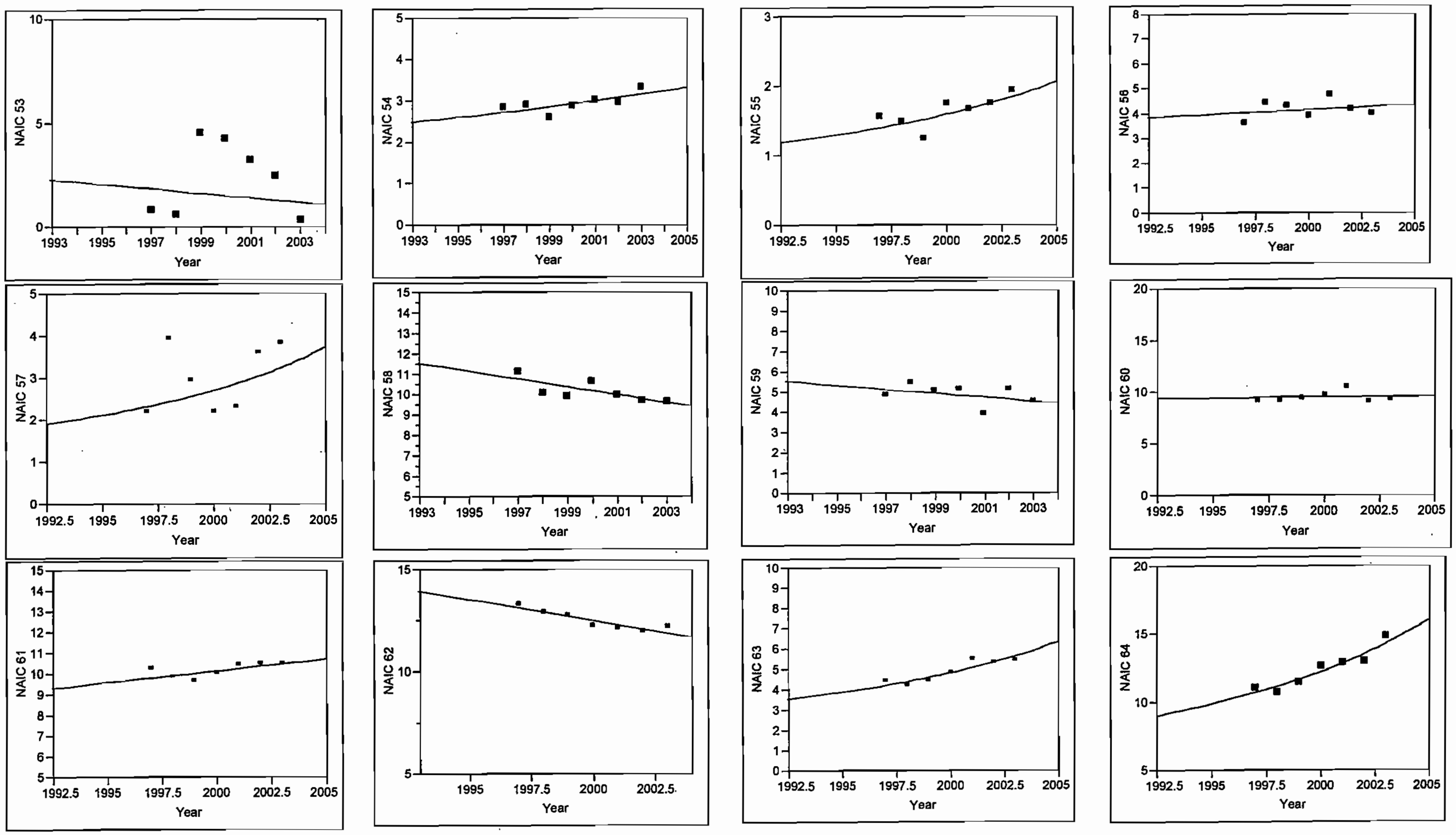
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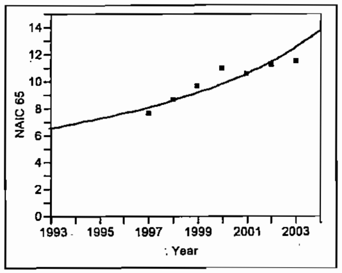
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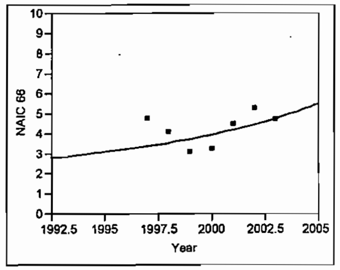
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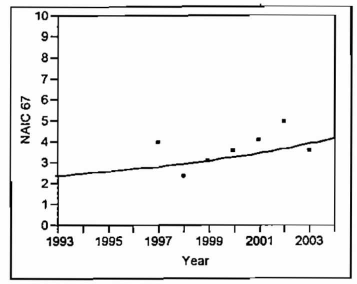
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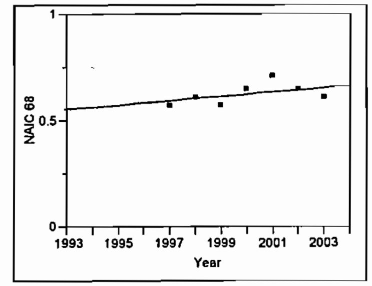
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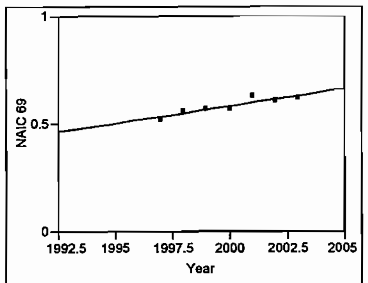
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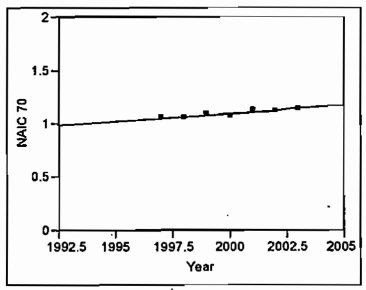
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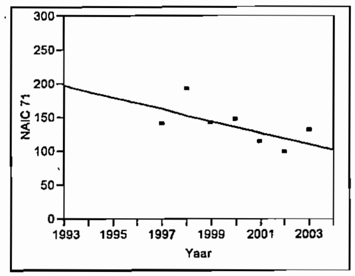
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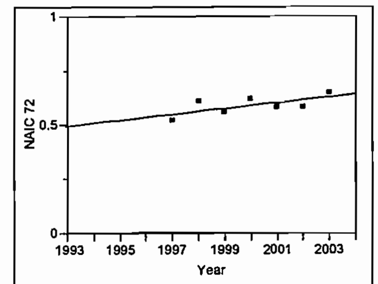
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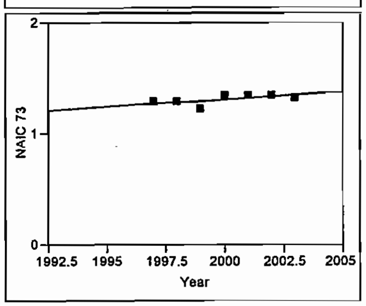
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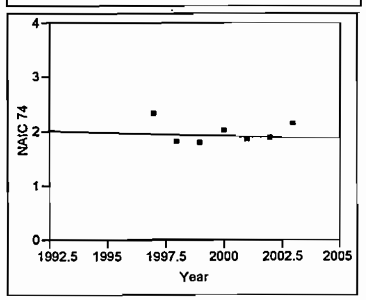
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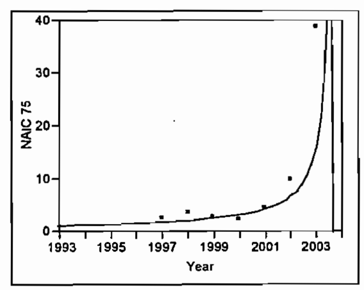
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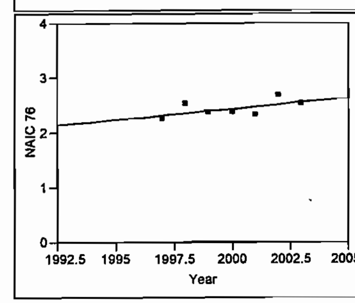
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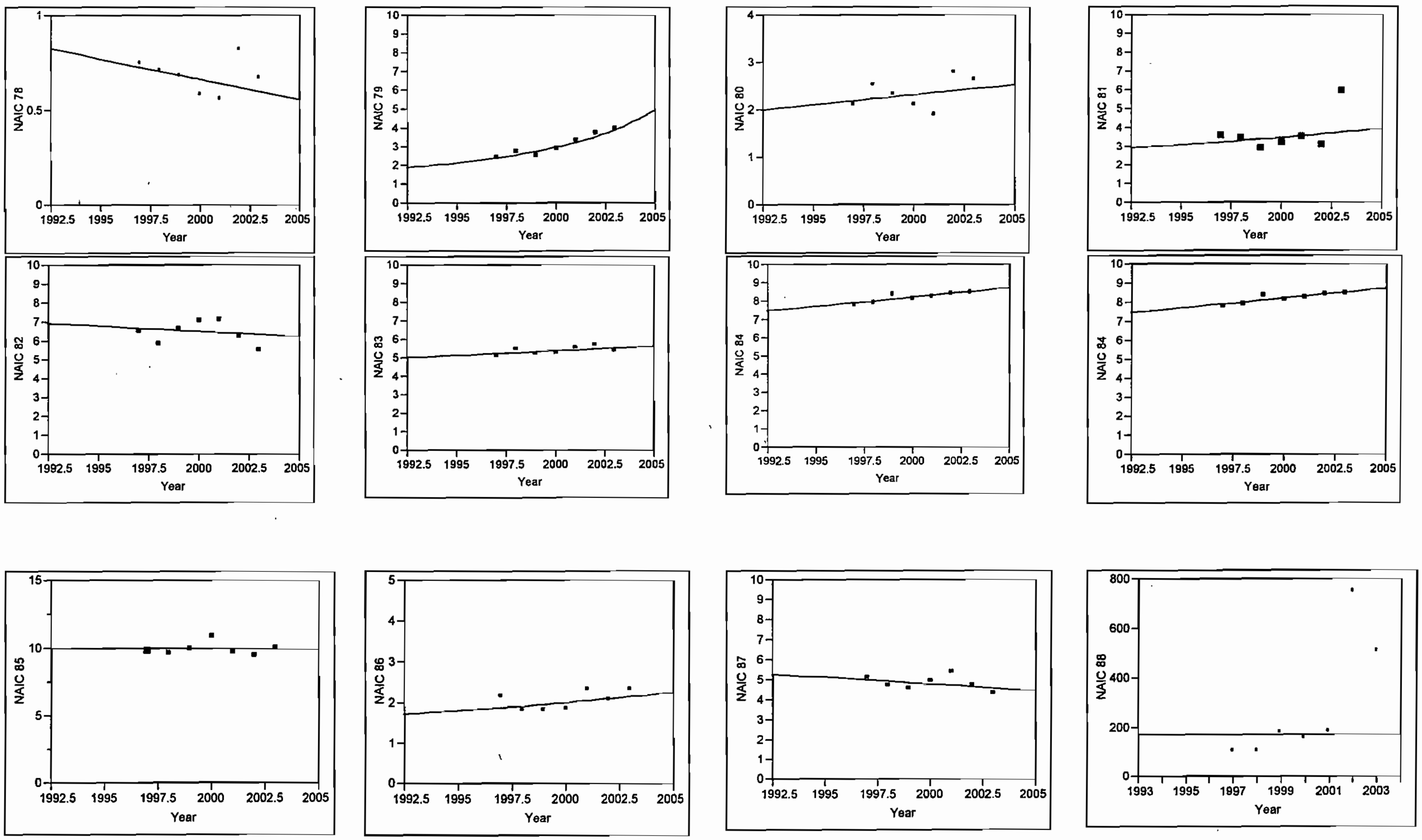
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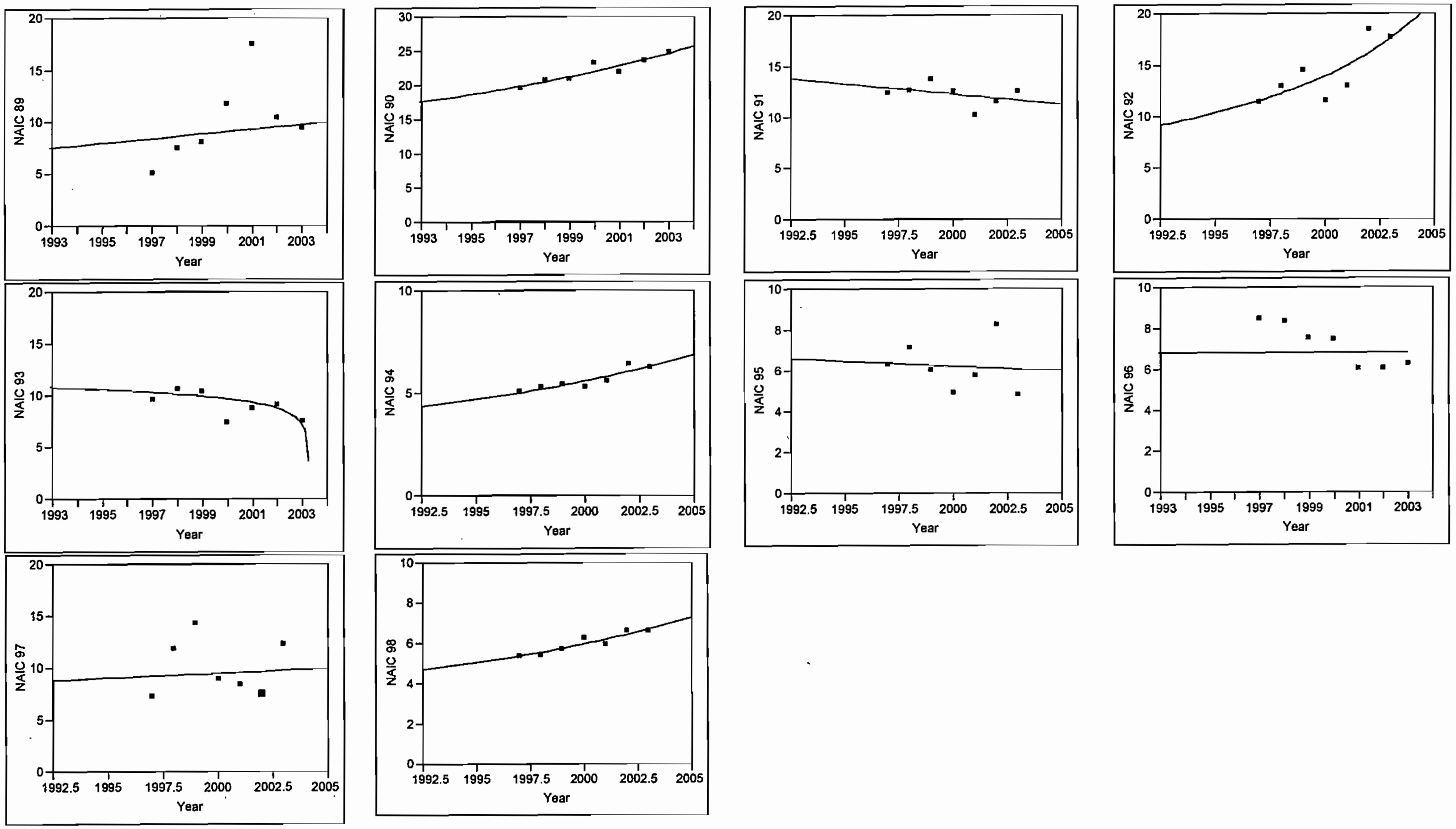
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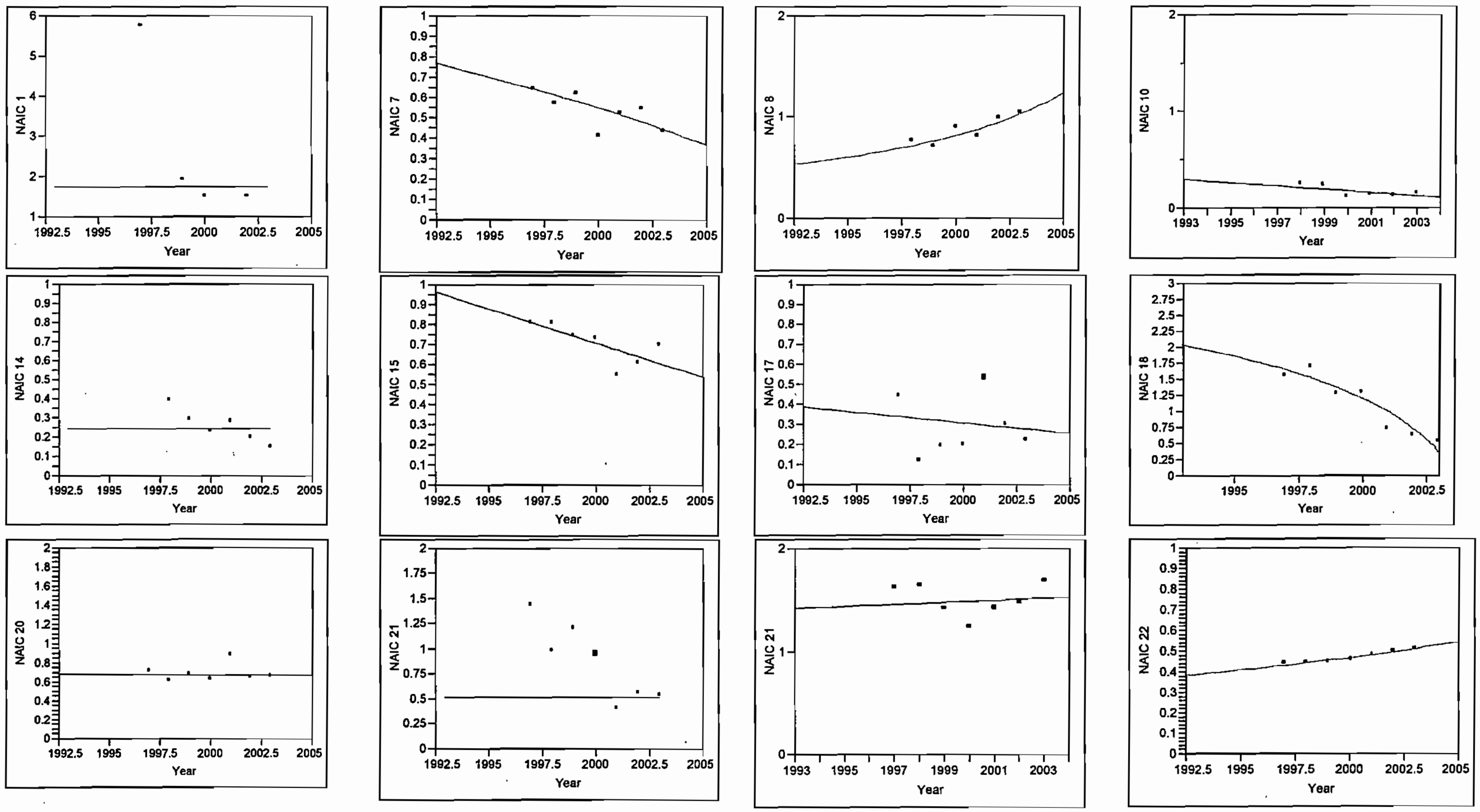
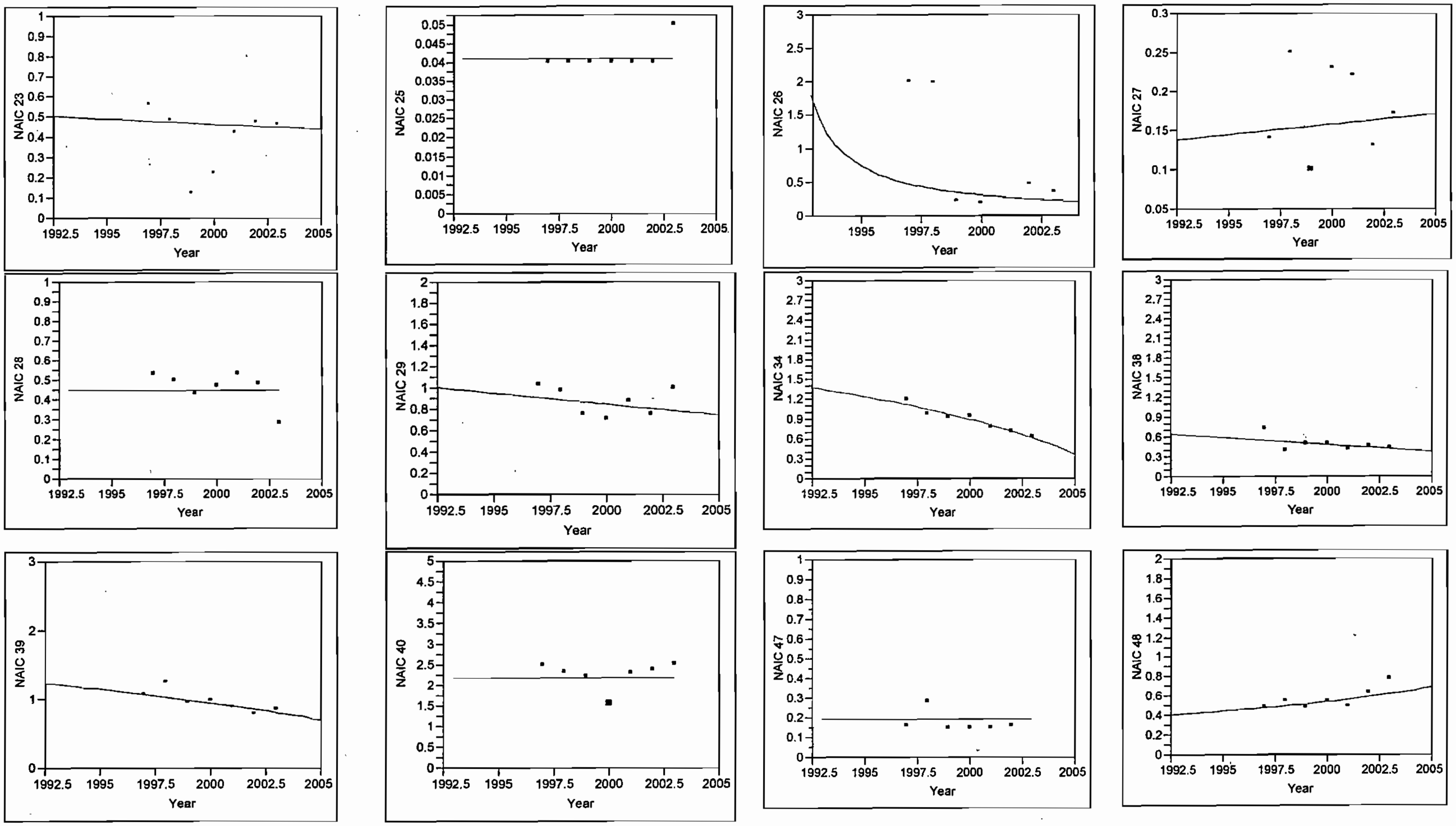
NAIC 98
Year

Regression Plots Used to Estimate Value to Weight Ratios for Rail

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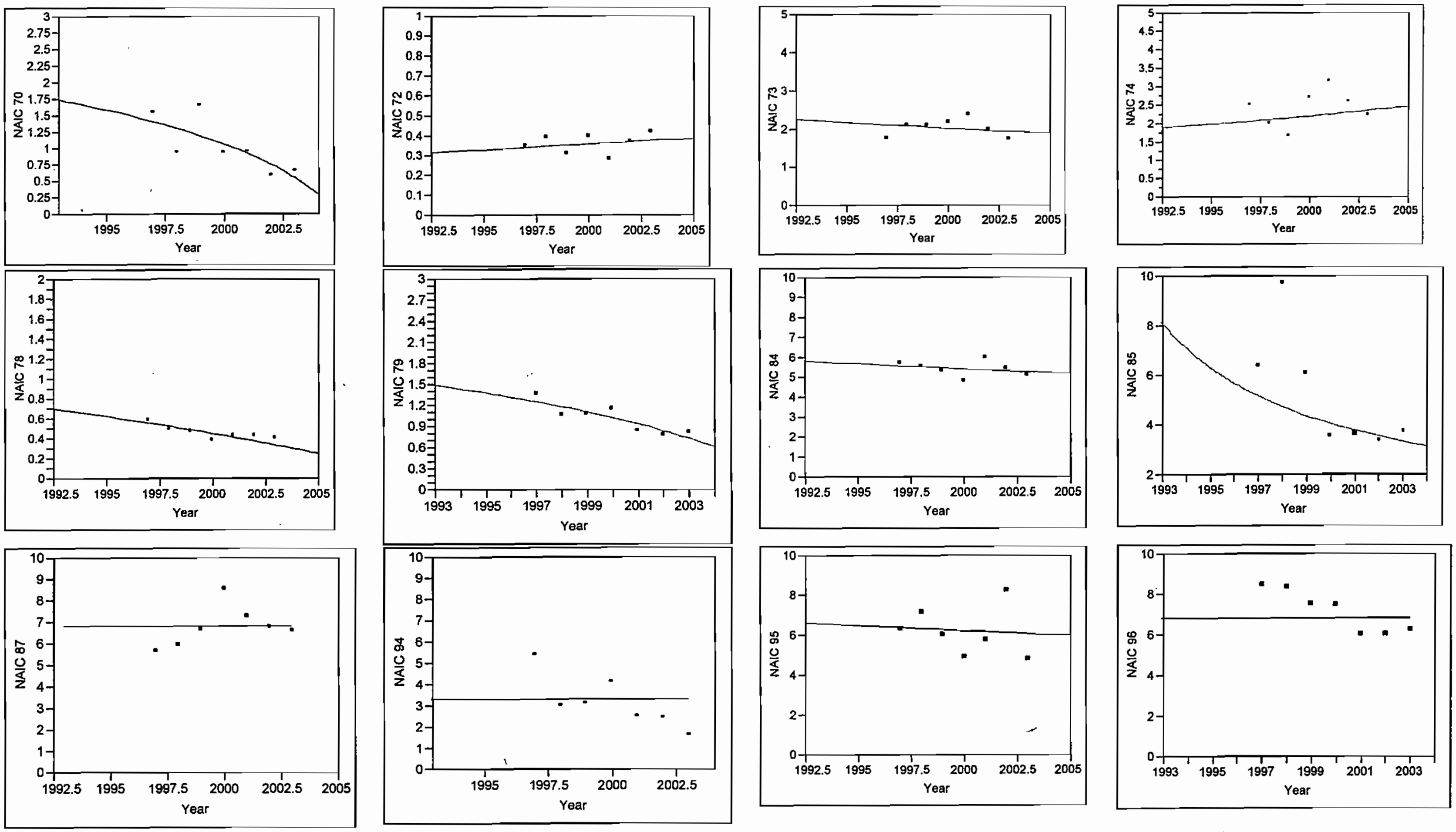
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NAIC 96
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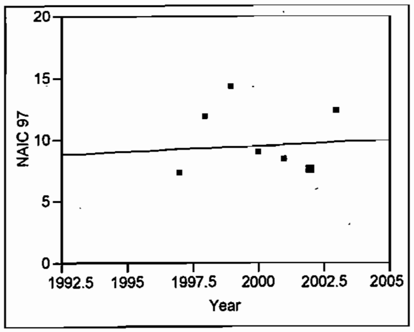
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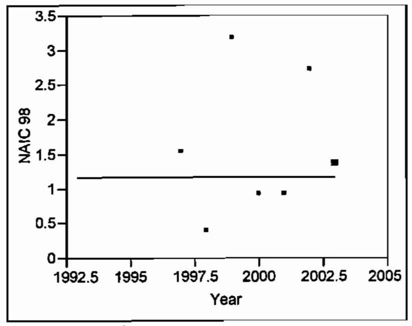
20
15
10
5
0
1992.5
1995
1997.5
2000
2002.5
2005
Year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3.5
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2
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1
0.5
0
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1995
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2000
2002.5
2005
Year