UNDERSTANDING U.S. ETHANOL CONSUMPTION AND ITS IMPLICATIONS FOR POLICY: A STUDY OF THE IMPACT OF STATE-LEVEL INCENTIVES

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Policies to promote ethanol consumption were implemented on both the federal and state levels during the past decade. Several new biofuel incentives and regulations are expected to be enacted in the near future. Understanding current ethanol consumption is an important first step in assessing the impacts of enacted legislation and formulating sound economic policies that will promote ethanol consumption. Despite the important implications for policy, our understanding of ethanol consumption patterns is quite limited. This Article examines historical state-level ethanol consumption data to understand how ethanol consumption responds to regional macroeconomic conditions and incentives set by state governments. Our empirical analysis reveals that changes in ethanol consumption patterns occurred before and after 2005, the year the original Renewable Fuel Standard (RFS) program was signed. Prior to 2005, ethanol consumption responded to incentives set by state governments. These relationships weakened after 2005, however, and ethanol consumption became more uniform across states. These empirical findings can be interpreted as indicating the emergence of a nascent, national market for biofuels. If biofuels are no longer simply local phenomena, some coordination in policy making between the federal and the state governments is necessary to promote biofuels consumption within the United States. Furthermore, technological progress in biofuel

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production is needed to serve as an engine for the growth of biofuel consumption.

I. INTRODUCTION

Biofuels have recently emerged as one of several promising options for reducing greenhouse gas emissions through the partial replacement of fossil fuels. In the United States, the Environmental Protection Agency (EPA) is in charge of developing a Renewable Fuel Standard (RFS) program that mandates a minimum level of biofuel consumption between 2006 and 2022. Under the RFS, it is mandated that the United States consume 36 billion gallons of biofuels in the year 2022.[1] This number is approximately three times as large as the total amount of ethanol consumption in the United States in 2009.[2] Not surprisingly, promotion policies are found outside the federal domain. Several state governments have implemented, and are planning to implement, their own biofuel regulations and programs that incentivize state-level ethanol consumption. In Minnesota, for example, mandatory blending laws require that gasoline contain at least 10% ethanol.[3] In Kansas, the tax rate on E85 is $0.17 per gallon whereas the tax rate on motor gasoline is $0.24 per gallon.[4] Alternative fuel vehicle credits or subsidies also are popular state-level policies for incentivizing biofuel consumption.

Understanding biofuel consumption is an important first step in formulating sound economic policies designed to promote biofuels and assess the impacts of those laws. Despite the important implications, both researchers and legislators appear to have only a vague understanding of biofuel consumption patterns. This study attempts to advance our knowledge in this field by examining historical state-level ethanol consumption data in the United States. More specifically, we examine the data in order to understand how ethanol consumption responds to regional macroeconomic conditions and incentives set by state governments. Achieving this research objective required compiling data from the State Energy Data System, Regional Economic Account Data, Petroleum Market Annual, and Alternative Fuel and Advanced Vehicle Data

1. Energy Independence & Security Act of 2007, Pub. L. No. 110-140, § 202, 121 Stat. 1492, 1521–24 (codified at 42 U.S.C. § 7545(o) (Supp. II 2009)); Regulation of Fuels and Fuel Additives: Changes to Renewable Fuel Standard Program, Final Rule, 75 Fed. Reg. 14,670, 14,673 (Mar. 26, 2010) (to be codified at 40 C.F.R. pt. 80) ("The EISA fuel program, hereafter referred to as RFS2, mandates the use of 36 billion gallons of renewable fuel by 2022—a nearly five-fold increase over the highest volume specified by EPAct.").

2. U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, PUB. NO. 0384, ANNUAL ENERGY REVIEW 2009, at 329 (2010), http://www.eia.doe.gov/aer/pdf/aer.pdf (reporting that 10,847 million gallons of ethanol were consumed in 2009).

3. MINN. STAT. ANN. § 239.791(a) (West 2010) ("All gasoline sold or offered for sale in Minnesota must contain at least . . . 10.0 percent denatured ethanol by volume; or . . . the maximum percent of denatured ethanol by volume authorized in a waiver granted by the United States Environmental Protection Agency.").

4. KAN. STAT. ANN. § 79-34,141 (West Supp. 2008) (taxing regular fuel at $0.24 per gallon while taxing E85 fuel at $0.17 per gallon).

during the period from 2000 through 2008.[5] We also made extensive use of panel data estimation techniques to analyze state-level and per capita ethanol consumption patterns.

Our empirical analysis reveals several interesting ethanol consumption patterns. Per capita ethanol consumption varies more widely across the states than per capita motor gasoline consumption. The dispersion of per capita ethanol consumption, however, becomes smaller and smaller over time. The observed trend implies that per-capita ethanol consumption eventually will become uniform across all states. This parallels the current status of per capita motor gasoline consumption. We also find a remarkable change in ethanol consumption patterns before and after 2005, the year the original RFS was signed. Prior to 2005, per capita ethanol consumption responded to state-level incentives and regulations such as blended fuel tax reductions and mandatory blending requirements. Such incentives, however, became less effective for promoting per capita ethanol consumption after 2005. Strikingly, our examination of the data reveals that the five states that have the fastest-growing ethanol consumption rates have rarely implemented ethanol consumption policies. The data instead show that a law of convergence governs growth in ethanol consumption—state-level ethanol consumption grows at a faster rate where the level of state-level ethanol consumption is smaller to begin with.

Our findings provide a fresh view regarding the effectiveness of biofuel policies at both the federal and state levels. First, our results suggest the importance of considering possible complementary and substitutive effects between federal- and state-level policies because such policies cannot be fully independent of each other. Therefore, some coordination between the federal and state governments will increase economic welfare by avoiding the redundancies of substitutable policies or by exploiting complementarity among policies. Second, our findings suggest that an approach in which biofuels promotion policies are designed differently from state to state, as opposed to applying a uniform policy to all fifty states, is worthy of consideration. This insight derives from our finding that ethanol demand in states which have small amounts of current use tends to grow at a faster rate than consumption in other states. Facilitating a convergence process of ethanol consumption in these low-demand states may encourage U.S. aggregate biofuel consumption to increase in a less costly manner and/or at a faster rate. Finally, an important long-run implication can be drawn from our findings regarding a law of convergence. Ethanol consumption growth eventually will enter a steady state unless technological breakthroughs take place in the biofuels

5. *See generally Alternative Fuels & Advanced Vehicles Data Center*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/ (last updated Oct. 25, 2010); BUREAU OF ECON. ANALYSIS, U.S. DEP'T OF COMMERCE, http://www.bea.gov/ (last modified Jan. 28, 2011); *Renewable & Alternative Fuels Analysis*, U.S. ENERGY INFO. ADMIN., http://www.eia.doe.gov/oiaf/renewable.html (last visited Jan. 29, 2011); ENERGY.GOV, http://www.energy.gov/index.htm (last visited Jan. 29, 2011).

production sector. Therefore, our research also indicates the importance of technological progress in the biofuels production sector.

The remainder of this paper is organized as follows. Part II briefly describes current state-level incentive programs that inform the regulatory environment on the state level and help interpret empirical results. Part III presents descriptive statistics and estimation results from our panel data that were used to obtain useful insights concerning ethanol consumption patterns. In order to carry out empirical analyses, we treat state-level heterogeneities by employing random- and fixed-effects models. Part IV discusses policy implications based on our estimation results, and Part V concludes the paper.

II. FEDERAL AND STATE POLICIES FOR PROMOTING ETHANOL CONSUMPTION

The U.S. Congress passed the Energy Policy Act in 2005, which charged the EPA with developing and implementing the RFS.[6] The RFS stipulates that obligated parties, such as gasoline producers and importers, produce or purchase a specific amount of renewable biofuel every year between 2006 and 2012.[7] In December of 2007, the Energy Independence and Security Act of 2007 amended the RFS to extend the period of volumetric requirements through the year 2022.[8]

Table 1 shows the total volumetric requirements of renewable fuel consumption under the amended RFS and the applicable volume of each subcategory.[9] The total consumption requirement is 4 billion gallons in 2006, and this amount progressively increases over time to require the consumption of 36 billion gallons by 2022.[10] We also see that the requirements for biofuel and cellulosic biofuel increase disproportionately over time, which reflects the intention of promoting renewable fuels, other than ethanol, which are derived from corn starch.[11] Grain-based ethanol demand met the required levels from 2006 to 2009,[12] but the commercialization of second-generation biofuels, such as cellulosic biofuels derived from feedstocks such as switchgrass, miscanthus, corn stover, wheat straw and the like, has not progressed as rapidly as the EPA expected. Thus, despite having originally set the cellulosic standard at 100 million ethanol-equivalent gallons for 2010, in February 2010 the

6. Energy Policy Act of 2005, Pub. L. No. 109–58, § 1501, 119 Stat. 594, 1067 (2005).

7. *Id.* at 1069.

8. Energy Independence & Security Act of 2007, Pub. L. No. 110-140, § 202, 121 Stat. 1492, 1521–24 (codified at 42 U.S.C. § 7545(o) (Supp. II 2009)).

9. *Id.* Note that the volumetric requirements (i.e., mandated demand) for cellulosic biofuel are more than threefold compared to the requirement for advanced biofuel in 2022. *See infra* Table 1. In 2009, Congress introduced a bill that expands the term "cellulosic biofuel" to include any cultivated algae, cyanobacteria, or lemna. Algae-Based Renewable Fuel Promotion Act of 2010, H.R. 4168, 111th Cong. (2d Sess. 2010) (as placed on the calendar of the Senate, Nov. 15, 2010).

10. Energy Independence & Security Act § 202.

11. *Id.*

12. *See* U.S. ENERGY INFO. ADMIN., *supra* note 2, at 329.

EPA announced a change that required the consumption of only 6.5 million gallons in 2010.[13]

TABLE 1
VOLUMETRIC REQUIREMENTS UNDER THE RFS
(IN BILLIONS OF GALLONS)

Year	Total Renewable Fuel	Cellulosic Biofuel	Advanced Biofuel
2006	4.00		
2007	4.70		
2008	9.00		
2009	11.10		0.60
2010	12.95	0.10	0.85
2011	13.95	0.25	1.10
2012	15.20	0.50	1.50
2013	16.55	1.00	1.75
2014	18.15	1.75	2.00
2015	20.50	3.00	2.50
2016	22.25	4.25	3.00
2017	24.00	5.50	3.50
2018	26.00	7.00	4.00
2019	28.00	8.50	4.50
2020	30.00	10.50	4.50
2021	33.00	13.50	4.50
2022	36.00	16.00	5.00

Note: Total renewable fuel is the sum of volumetric requirements of corn-based renewable fuel, advanced biofuel, cellulosic biofuel, and biomass-based diesel. The volumetric requirement for biomass-based diesel is not reported in the table.

In addition to federal initiatives, several states have implemented their own incentive programs that are intended to promote ethanol consumption (Tables 2.a and 2.b).[14] Alternatively, several states have incentivized producers, distributors, and retailers by reducing their relative tax rates per gallon sold. In general, three policy instruments have been used to influence consumers' motor fuel decisions. First, several tax cre-

13. OFFICE OF TRANSP. AND AIR QUALITY, U.S. ENVTL. PROT. AGENCY, PUB. NO. EPA-420-F-10-007, REGULATORY ANNOUNCEMENT: EPA FINALIZES REGULATIONS FOR THE NATIONAL RENEWABLE FUEL STANDARD PROGRAM FOR 2010 AND BEYOND 1, 3–4 (2010), http://www.epa.gov/oms/renewablefuels/420f10007.pdf.

14. *See infra* Tables 2.a and 2.b.

dit incentives are being employed that seek to change the effective prices paid by the consumers of motor vehicle fuels. This policy instrument is intended to induce consumers to purchase more ethanol fuels by creating a tax difference between ethanol and fossil fuels. In Alaska, Illinois, Kansas, Michigan, Minnesota, and Oregon, consumers can receive credits or tax benefits for the purchase of E85 fuels relative to conventional motor gasoline. Incentives range from a $0.06 per gallon discount to a total waiver of state gas taxes on alternative fuels.[15] Tax benefits are not limited to E85 fuel. In Idaho and Illinois, the state tax rate on gasohol[16] is lower than the tax on conventional motor gasoline.[17] For example, a state tax rate on motor gasoline may be $0.25 per gallon,[18] whereas a state tax rate on gasohol may be $0.025 lower.

The second type of policy instrument requires ethanol blending. In this policy group, state governments set minimum ethanol consumption targets within the state. Mandatory ethanol blending is quite similar to the RFS. A notable difference is that the minimum ethanol consumption target can increase or decrease with respect to the amount of motor gasoline sold in the case of mandatory blending, but is, by and large, predetermined in the latter case of the RFS. In Minnesota, gasoline must contain at least 10% ethanol.[19] As discussed in Brown et al., several states follow Minnesota's plan and employ mandatory blending.[20] As of 2010, states that have required mandatory blending, or plan to do so, are Florida, Hawaii, Iowa, Louisiana, Missouri, Montana, and Washington.[21] Several states have mandatory blending policies in place that are only triggered when the state produces a threshold amount of ethanol in a given year.[22] Finally, several states have exempted premium gasoline from

15. ALASKA STAT. § 43.40.010(a)(4)(A) (2008) (discounting biofuel taxes by $0.06); 35 ILL. COMP. STAT. 105/3-10 (2006) (waiving state fuel tax for biodiesel blends greater than or equal to 10%); KAN. STAT. ANN. §§ 79-34,171 to 79-34,176 (West Supp. 2008) (creating state fund pay incentives to retailers of biodiesel of up to $0.065 per gallon sold); MICH. COMP. LAWS ANN. § 207.1008 (West 2010) (discounting biofuel taxes by $0.07); MINN STAT. ANN. § 296A.07 (West 2010) (discounting biofuel taxes by $0.725); OR. REV. STAT. § 315.465 (2009) (allowing Oregon residents an income tax rebate of up to $0.50 per gallon of blended fuel purchased, up to $200 per registered motor vehicle, annually).

16. Gasohol generally is defined as a blend of finished motor gasoline containing alcohol at a concentration between 5.7% and 10% by volume. 26 C.F.R. § 48.4081-6(b)(2)(i)(A) (2009) ("Gasohol is a mixture of gasoline and alcohol that is 10 percent gasohol, 7.7 percent gasohol, or 5.7 percent gasohol . . . .").

17. IDAHO CODE ANN. § 63-2401(10) (Supp. 2010); 35 ILL. COMP. STAT. 105/3-10 (Supp. 2007) (limiting the applicability of the state tax on gasohol based on volume sold).

18. *E.g.*, IDAHO CODE ANN. § 63-2402 (taxing motor fuels at $0.25 per gallon).

19. MINN. STAT. ANN § 239.791(a).

20. *See* E. BROWN ET AL., NAT'L RENEWABLE ENERGY LAB., U.S. DEP'T OF ENERGY, PUB. NO. TP-640-41075, UNDERSTANDING AND INFORMING THE POLICY ENVIRONMENT: STATE-LEVEL RENEWABLE FUELS STANDARDS 22–25 (2007), http://www.nrel.gov/docs/fy07osti/41075.pdf.

21. *See id.*; *see also* FLA. STAT. ANN § 526.203(2) (West Supp. 2010).

22. *See, e.g.*, *Renewable Fuels Mandate*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/laws/law/PA/6486 (last updated Jan. 4, 2011) ("All diesel fuel sold in Pennsylvania must contain at least 2% biodiesel (B2) one year after in-state production of biodiesel reaches 40 million gallons. The mandated biodiesel blend level will continue to increase according to the following schedule: 5% biodiesel (B5) one year after in-state production of biodiesel reaches 100 million gallons; 10% biodiesel (B10) one year after in-state production of biodiesel reaches 200 million gallons; and 20% biodiesel

blending requirements, apparently because of the lower miles per gallon ethanol blends earn.[23]

The third type of policy instrument is alternative fuel vehicle credits/subsidies. This policy instrument indirectly stimulates ethanol consumption. Motor vehicles and fuels are complementary goods for consumers. That is, consumers need both motor vehicles and fuels to enjoy the benefits that can be derived from driving their motor vehicles. Therefore, the widespread use of ethanol-driven cars can increase ethanol consumption. In fact, the introduction of flexible fuel cars helped spur ethanol consumption in Brazil.[24] In Illinois, for example, consumers can obtain a vehicle rebate for 80% of the incremental costs of the alternative fuel vehicle, up to a limit of $4000.[25] In addition to Illinois, alternative fuel credits have been, or currently are, available in Colorado, Georgia, Kansas, New York, and Oregon.[26] Several other states provide incentives for state agencies to use alternative fuel vehicles, and there is a trend toward requiring school buses to convert to alternative fuel.[27] Though states are implementing substantial, financially-oriented approaches to increasing ethanol consumption, smaller-scale measures have been attempted as well. For example, Colorado and Virginia allow some alternative fuel vehicles to use the high occupancy vehicle lanes even when they carry single passengers.[28] California, Hawaii, Massachusetts, Minnesota, and New York have similar legislation pending.[29] On the other hand, West Virginia has expressly prohibited its political subdivisions from incentivizing the production of alternative fuel.[30] Despite West Virginia's prohibition, however, incentives appear to be increasing in popularity elsewhere. A study conducted in 2007 showed that only ten states took part in RFS,[31] but our recent research shows that nineteen

(B20) one year after in-state production of biodiesel reaches 400 million gallons."); *see also* E. BROWN ET AL., *supra* note 20, at 26–28 (noting that Idaho, Michigan, and Oregon made plans to require blending after threshold levels of ethanol production had been met).

23. *See, e.g.*, MO. REV. STAT. § 414.255(5)(2) (West Supp. 2010) (exempting premium gasoline from blending requirements).

24. *Country Analysis Briefs: Brazil*, ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, http://www.eia.doe.gov/cabs/Brazil/Full.html (last updated Jan. 2011) (discussing flexible-fuel vehicles in the context of Brazil's presence as "one of the largest producers of ethanol in the world").

25. 415 ILL. COMP. STAT. 120/30 (2006).

26. COLO. REV. STAT. ANN. § 39-22-516 (West Supp. 2009); GA. CODE ANN. § 48-7-40.16(b) (2010); KAN. STAT. ANN. § 79-32,201 (Supp. 2008); N.Y. TAX LAW § 187-b (McKinney Supp. 2010); OR. REV. STAT. § 469.170 (2009).

27. *See, e.g.*, ARIZ. REV. STAT. ANN. § 15-349 (2009); CONN. GEN. STAT. ANN. § 14-164o (West 2006); W. VA. CODE ANN. § 18-9A-7 (LexisNexis 2008); *Grant and Incentive Programs*, SAN JOAQUIN VALLEY: AIR POLLUTION CONTROL DIST., http://www.valleyair.org/Grant_Programs/GrantPrograms.htm (last visited Jan. 29, 2011); *New Jersey Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/NJ/ETH (last updated Feb . 19, 2010).

28. *2009 State Energy Legislative Updates*, NAT'L CONFERENCE OF STATE LEGISLATURES, http://www.ncsl.org/?tabid=18321 (last visited Jan. 29, 2011).

29. *Id.*

30. W. VA. CODE ANN. § 8-27A-3.

31. *See* E. BROWN ET AL., *supra* note 20, at 22 ("As of December 2006, there are 10 states with implemented renewable fuels standard (RFS) policies.").

states now have such standards. Still more laws are expected to be proposed in 2011.[32]

Table 2.a summarizes the statutes behind each law, their dates of enactment, and their respective dates of compliance. This data was compiled by conducting a state-by-state survey through the Department of Energy's Alternative Fuels and Advanced Vehicles Data Center. Once we took note of specific laws, we verified the regulation by locating the state code. Statutory language was also used to identify the dates of enactment and compliance. Table 2.b summarizes each state's type of law (e.g., an E85 Tax Incentive) and offers a brief description of each law's requirements. This data also was pulled from a state-by-state survey and verified by examining specific statutory language.

32. *See California Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/CA/ETH (last updated Feb. 19, 2010); *Minnesota Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/MN/ETH (last updated Feb. 19, 2010); *Nebraska Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/NE/ETH (last updated Feb. 19, 2010).

TABLE 2.A
SUMMARY OF STATE INCENTIVES—DATES OF ENACTMENT, DATES OF COMPLIANCE, AND STATUTORY AUTHORITY

Summary of States with RFS (RFS = E10 or E85 Tax Breaks, Mandatory Blending Laws, and AFV Incentives)					
State	Law Type	Year of Enactment	Year of Compliance or Activation	Law	Justification for Law as Written in Legislation (DNS = Did Not State Goal in Legislation)
Alaska	E10 Tax Incentive	1997	1997	ALASKA STAT. § 43.40.010(a)(4)(A) (2008)	Promote ethanol consumption
Florida	Mandatory Blending	2008	2010	FLA. STAT. § 526.201–.207 (Supp. 2010)	Economy, green house gas reduction, reduction of dependence on foreign oil, health and quality of life
Georgia	AFV Incentive	2003	2003	GA. CODE ANN. § 48-7-40.16(b) (2009)	Not in legislation
Hawaii	Mandatory Blending	1994, Amended in 1997, 2002, 2006	2004	HAW. REV. STAT. ANN. § 486J-10 (LexisNexis 2009)	Economy
Illinois	E85 Tax Incentive^	2003	2003	35 ILL. COMP. STAT. 105/3-10, 105/3-44 (2009)	DNS
	AFV Incentive	1995; Amended in 1998, 2002, 2005, 2006, 2009	1997	415 ILL. COMP. STAT. 120/30 (2009)	Use alternative energy, improve air quality

Continued on next page

TABLE 2.A—*Continued*

State	Law Type	Year of Enactment	Year of Compliance or Activation	Law	Justification for Law as Written in Legislation (DNS = Did Not State Goal in Legislation)
Kansas	E85 Tax Incentive	2007	2007	KAN. STAT. ANN. §§ 79-3401, 79-3490, 79-34,141 (2008)	DNS
	AFV Incentive	1995, Amended 1999, 2001	1996	KAN. STAT. ANN. § 79-32,201 (2008)	DNS
Louisiana	Mandatory Blending*	2006	Production Date	LA. REV. STAT. ANN. 3:4674(C)(1) (Supp. 2010)	Economy, reduction of dependence on foreign oils, environment
	AFV Incentive	2009	2009	LA. REV. STAT. ANN. 47:6035 (Supp. 2010)	DNS
Michigan	E85 Tax Incentive^	2006	2006	MICH. COMP. LAWS ANN. § 207.1008 (West 2010)	DNS
Minnesota	Mandatory Blending	2005	2005	MINN. STAT. ANN. § 239.791 (West 2010)	DNS
Missouri	Mandatory Blending	2006	2008	MO. REV. STAT. § 414.255 (Supp. 2010)	DNS
Montana	Mandatory Blending*	1993	1993	MONT. CODE ANN. § 15-30-2320 (2009)	DNS
	AFV Incentive	2005	Production Date	MONT. CODE ANN. § 82-15-121 (2009)	DNS

Continued on next page

TABLE 2.A—*Continued*

State	Law Type	Year of Enactment	Year of Compliance or Activation	Law	Justification for Law as Written in Legislation (DNS = Did Not State Goal in Legislation)
Nebraska	AFV Incentive	NA	NA	*Dollar and Energy Saving Loans*, NEB. ENERGY OFFICE, http://www.neo.ne.gov/loan/ (last visited Jan. 29, 2011)	DNS
New York	E85 Tax Incentive	2006	2006	N.Y. TAX LAW § 1115 (McKinney 2008)	DNS
Oklahoma	E85 Tax Incentive*	2005	2006	OKLA. STAT. tit. 68, § 500.10-1 (Supp. 2009)	DNS
	AFV Incentive	NA	NA	OKLA. DEP'T OF COMMERCE, ALTERNATIVE FUEL VEHICLE LOAN PROGRAM (AFV) (2009), *available at* http://www.okcommerce.gov/file/Alternative-Fuel-Vehicles-Loan_2063.doc	DNS
Oregon	Mandatory Blending	2007; Amended in 2009	2009	OR. REV. STAT. § 646.913 (2009)	DNS

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TABLE 2.A—*Continued*

State	Law Type	Year of Enactment	Year of Compliance or Activation	Law	Justification for Law as Written in Legislation (DNS = Did Not State Goal in Legislation)
Texas	AFV Incentive^	NA	NA	*Alternative Fuels and Technologies FAQ*, HOUSTON-GALVESTON AREA COUNCIL, http://www.houston-cleancities.org/alt_fuels&tech.htm (last visited Jan. 29, 2011)	Economic, environmental and energy security
Washington	Mandatory Blending	2006	2008	WASH. REV. CODE ANN. § 19.112.120 (West 2007)	Reduce dependence on foreign oil, health, rural economy
Policies are summarized using online information from the U.S. Department of Energy and confirmed with the relevant state statutes or codes					
* Law not yet operative					
^ Not an exact fit to law type: in Illinois a tax discount of 5% is applied to blended gasoline, and in Michigan the tax discount is about 3.68%					

TABLE 2.B
SUMMARY OF STATE INCENTIVE REGULATIONS AND PROGRAMS

Summary of States with RFS		
State	Law Type	Summary of Law
Alaska	E10 Tax Incentive^	Discount of $0.06 during certain times
Florida	Mandatory Blending*	Starting on December 31, 2010 all gas must have 10% ethanol
Georgia	AFV Incentive	Income tax credit for 10% of the cost to purchase or lease (or convert) an alternative fuel vehicle with a $2500 cap
Hawaii	Mandatory Blending	Eighty-five percent of gas must contain 10% ethanol
Illinois	E85 Tax Incentive	Sales taxes do not apply to ethanol blended fuels that contain 70%–90% ethanol until December 31, 2013
	AFV Incentive	Credit of 80% of the incremental cost of purchasing an alternative fuel vehicle or 80% of the conversion cost will be provided, up to $4000
Kansas	E85 Tax Incentive	The minimum motor vehicle fuel tax rate on E85 is $0.17 per gallon, compared to the conventional motor fuel tax rate of $0.24 per gallon that is effective until July 1, 2020
	AFV Incentive	Income tax credit for 40% of the incremental or conversion cost of AFV (50% before 2005)
Louisiana	Mandatory Blending*	When the state produces 50 million gallons of a renewable fuel and its cost is equivalent to that of regular gasoline, 2% of gasoline sold must be ethanol
	AFV Incentive	Tax credit for 50% of cost for conversion or incremental purchase cost of an alternative fuel vehicle
Michigan	E85 Tax Incentive	Discount of $0.07 per gallon on E70 and higher
Minnesota	Mandatory Blending	All gas must be 10% ethanol, which increases to 20% by 2013 unless ethanol has already replaced 20% of all motor vehicle fuel sold in the state or the United States
		Continued on next page

TABLE 2.B—*Continued*

State	Law Type	Summary of Law
Missouri	Mandatory Blending	All motor gasoline must contain 10% ethanol unless it is premium gasoline or otherwise more expensive to the distributor than regular fuel
Montana	Mandatory Blending*	All motor gasoline sold must be blended with 10% agriculturally derived, denatured ethanol by volume within one year of the state producing 40 million gallons of ethanol in a year
	AFV Incentive	Tax credit of up to 50% or $500 for converting a vehicle to alternative fuels
Nebraska	AFV Incentive	Low-cost loans for purchase of an alternative fuel vehicle or conversion of conventional to an alternative fuel vehicle
New York	E85 Tax Incentive	E85 is exempt from state sales and use taxes until September 1, 2011
Oklahoma	E85 Tax Incentive^	Retailers can claim a tax credit of $0.16 per gallon of gas that has 15% ethanol or less *only* if they pass the discount to purchasers
	AFV Incentive	Private loan program with a 3% interest rate for converting private fleets to alternative fuel vehicles
Oregon	Mandatory Blending	All gasoline sold in the state must be blended with 10% ethanol (E10)
Texas	AFV Incentive^	Houston-Galveston area grants are available for up to 75% of the incremental cost of purchasing or clean fuel repowers
Washington	Mandatory Blending	Two percent of gasoline sold must be ethanol (can be increased if conditions are met)
Policies are summarized using online information from the U.S. Department of Energy and confirmed with the relevant state statutes and codes		
*Law not yet operative		
^Not exact law type: tax incentive does not apply automatically, rather certain conditions have to be met first (such as a specified amount of ethanol has to be produced in a given year)		

In theory, each policy instrument discussed above influences ethanol consumption patterns. Nevertheless, practical impacts can differ and diverge from the theoretical predictions, and therefore should be examined carefully by making use of data. Subsequent Sections will examine historical data on state-level U.S. ethanol consumption in order to investigate the actual role that these policy instruments play in determining ethanol consumption patterns.

III. EMPIRICAL ANALYSIS

A. Data and Methodology

The data in this study come from various sources. State-level ethanol consumption data are the most important data used in our empirical analyses and these data are gathered from the State Energy Data System (SEDS), compiled by the U.S. Energy Information Administration. In conjunction with data on several energy sources, state-level ethanol consumption data are available for the years 1960 to 2008. We also compiled a series of state-level motor gasoline consumption data gathered from the SEDS in order to use gasoline consumption patterns as an aid for the interpretation of ethanol consumption data. We gathered regional macroeconomic indicators such as gross domestic product, farm income, and nonfarm income from the Regional Economic Account Data of the Bureau of Economic Analysis. In order to identify state-level ethanol consumption promotion policies, we first utilized the website of Alternative Fuels and Advanced Vehicles Data Center that is run by the U.S. Department of Energy. We then verified that data with existing state statutes.

In the context of this study, the unit of analysis is a state, and the data include fifty states and the District of Columbia. Our choice of a state as our unit of analysis is appropriate because the main purpose of this study is to examine how ethanol consumption responds to incentives set by state governments. We focus on examining state-level and per capita ethanol consumption patterns during the period of 2000 to 2008. This time frame was chosen primarily because a complete set of research variables of interest to us was available for this period of time. Another reason for our choice is to examine whether the RFS has impacted the effectiveness of state-level ethanol consumption promotion policies. The data set of this study is a panel, and there are nine observation points in time for each of fifty states and one district. Therefore, the maximum number of observations in our dataset is 459.

We exploit the panel nature of the data in our regression analyses in order to understand patterns of state-level and per capita ethanol consumption. Our basic estimating equation is given by

$$y_{it} = x_{it}\beta + \alpha_i + \varepsilon_{it}$$

where y_{it} is total or per capita ethanol consumption of state i at time t, and x_{it} is a vector of independent variables in which we are interested, such as macroeconomic indicators and ethanol consumption policy indicators. Our parameters of interest are β, and we report their estimates and standard errors. We use α_i to denote an unobservable timeinvariant, state-specific factor of state *i*, and ε_{it} indicates a random disturbance term of state *i* at time *t*.

We utilize two standard panel data estimation models—random- and fixed-effects models—to analyze ethanol consumption patterns.[33] The random-effects model is legitimate when α_i is not partially correlated with any of x_{it}, whereas the fixed-effects model should be favored against the random-effects model when an endogeneity problem is suspected.[34] Since a choice regarding these models is an empirical question, we carried out a Hausman test in order to decide which model is more appropriate to use as a basis for statistical inferences in the case of our data.[35]

B. A Variation in State-Level Ethanol Consumption

It is natural to assume that the level of ethanol consumption varies from state to state, but one will probably find it difficult to determine with true accuracy, in the absence of detailed analysis, *how* state-level ethanol consumption in the United States actually varies. Understanding variations in state-level ethanol consumption requires that this study begin with an analysis of descriptive statistics.

Table 3 presents key descriptive statistics concerning total ethanol consumption, per capita ethanol consumption, ethanol consumption per vehicle registration and the ratio of ethanol consumption to motor gasoline consumption for the year 2008. Table 3 shows the average value of state-level ethanol consumption in 2008 to be 189.9 million gallons per state. This number is approximately equivalent to the total amount of United States ethanol consumption in 1981,[36] and is about 7.5% of the average state-level motor gasoline consumption for 2008. The coefficient of variation of state-level ethanol consumption is 1.069, whereas the corresponding number for motor gasoline consumption is 1.067. These numbers suggest that the dispersion of state-level ethanol consumption is

33. A random-effects model is a generalized least square estimator imposing the assumption that an error structure is $\alpha + \varepsilon_{it}$. This estimator is not intended to fix a source of potential endogeneity problems. On the other hand, a fixed-effects model includes an individual dummy in an estimating equation to control for a potential source of endogeneity, in other words, the effects of α_i. *See* JEFFREY M. WOOLDRIDGE, ECONOMETRIC ANALYSIS OF CROSS SECTION AND PANEL DATA 272–74 (2002).

34. *See id.* at 284–88.

35. A Hausman test is a statistical test for endogeneity widely used in social science studies. Roughly speaking, the test is based on the idea that two alternative estimators are not different when there is no endogeneity. *Id.* at 118–23, 288–91; *see also* J.A. Hausman, *Specification Tests in Econometrics*, 46 ECONOMETRICA 1251 (1978).

36. *See* U.S. ENERGY INFO. ADMIN., *supra* note 2, at 329 (reporting that total ethanol consumption was 83 million gallons in 1981); *see also* JOSEPH DIPARDO, ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, OUTLOOK FOR BIOMASS ETHANOL PRODUCTION AND DEMAND 1 (2000), http://www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf ("Ethanol production in the United States grew from 175 million gallons in 1980 to 1.4 billion gallons in 1998, with support from Federal and State ethanol tax subsidies and the mandated use of high-oxygen gasolines.").

modest, given that unity is often used as a benchmark number for the dispersion measured by the coefficient of variation.[37]

One may point out that the level of state population can likely be attributed to the variation in state-level ethanol consumption. To minimize this influence, state-level ethanol consumption per capita and state-level ethanol consumption per vehicle registration are computed for the purpose of constructing key statistics. The coefficient of variation of per capita state-level ethanol consumption is 0.33 and the corresponding number is 0.31 for state-level ethanol consumption per vehicle registration. These coefficients of variation are significantly less than unity. This finding indicates that the size of a state's population contributes significantly to the dispersion of state-level ethanol consumption.

Statistics for the top five states also confirm the above insight. The fourth column of Table 3 shows that the top five states account for approximately 34% of the total U.S. ethanol consumption while the remaining 66% comes from the other forty-five states and one district. The same statistic for per capita ethanol consumption drops to 14.5%. Thus, we can infer that the distribution of state-level ethanol consumption is skewed, but the degree of skewness decreases when population effects are taken into account. The same inference can be reached when we use ethanol consumption per vehicle registration as an alternative measure.

It is possible that ethanol consumption is simply proportional to gasoline consumption since ethanol is used mainly as a gasoline additive. To examine this possibility, it is useful to examine the ratio of ethanol consumption to motor gasoline consumption. This ratio can be regarded as the upper boundary of the ethanol blending percentage because the ratio corresponds to the number obtained under the assumption that all ethanol is blended into motor gasoline. The coefficient of variation for this variable is 0.31 and similar in magnitude to that of ethanol consumption per capita and per vehicle registration. This implies that ethanol consumption is positively correlated with gasoline consumption, but the correlation is not perfect.

37. The coefficient of variation is a measure of dispersion normalized by dividing the standard deviation by the mean of a particular variable. When a probability distribution has the same mean and standard deviation (e.g., exponential distribution), the coefficient of variation is 1.

TABLE 3[38]
DESCRIPTIVE STATISTICS ON STATE-LEVEL ETHANOL CONSUMPTION IN 2008

	Average	Standard Deviation	Coefficient of Variation	Top Five States Percentage	Min.	Max.
Total (Million Gallons)	189.9	203.0	1.07	33.9	6.0	1006.3
Per Capita (Gallons)	31.9	10.4	0.33	14.5	9.7	50.2
Per Vehicle Registration (Gallons)	38.8	11.9	0.31	13.7	9.7	55.1
Ratio of Ethanol to Motor Gasoline	0.07	0.02	0.31	NA	0.02	0.10

California ranks first in the country for state-level ethanol consumption, but also ranks first for state population (Table 4). California's large population makes it rank fortieth in terms of per capita ethanol consumption and thirty-ninth in terms of ethanol consumption per vehicle registration.[39] Minnesota takes first place in the United States in these two categories. In regard to the ratio of ethanol to gasoline, Illinois ranks first in the country, and Minnesota is a close second.

TABLE 4[40]
RANKING OF ETHANOL CONSUMPTION IN 2008

	Ethanol Consumption				Population
	Total	Per Capita	Per Vehicle Registration	Ratio to Gasoline	
1st	California	Minnesota	Minnesota	Illinois	California
2nd	Texas	South Dakota	Nevada	Minnesota	Texas
3rd	Florida	North Dakota	New Jersey	Rhode Island	New York
4th	Illinois	Oklahoma	Indiana	South Dakota	Florida
5th	Ohio	Kentucky	Arizona	Wisconsin	Illinois

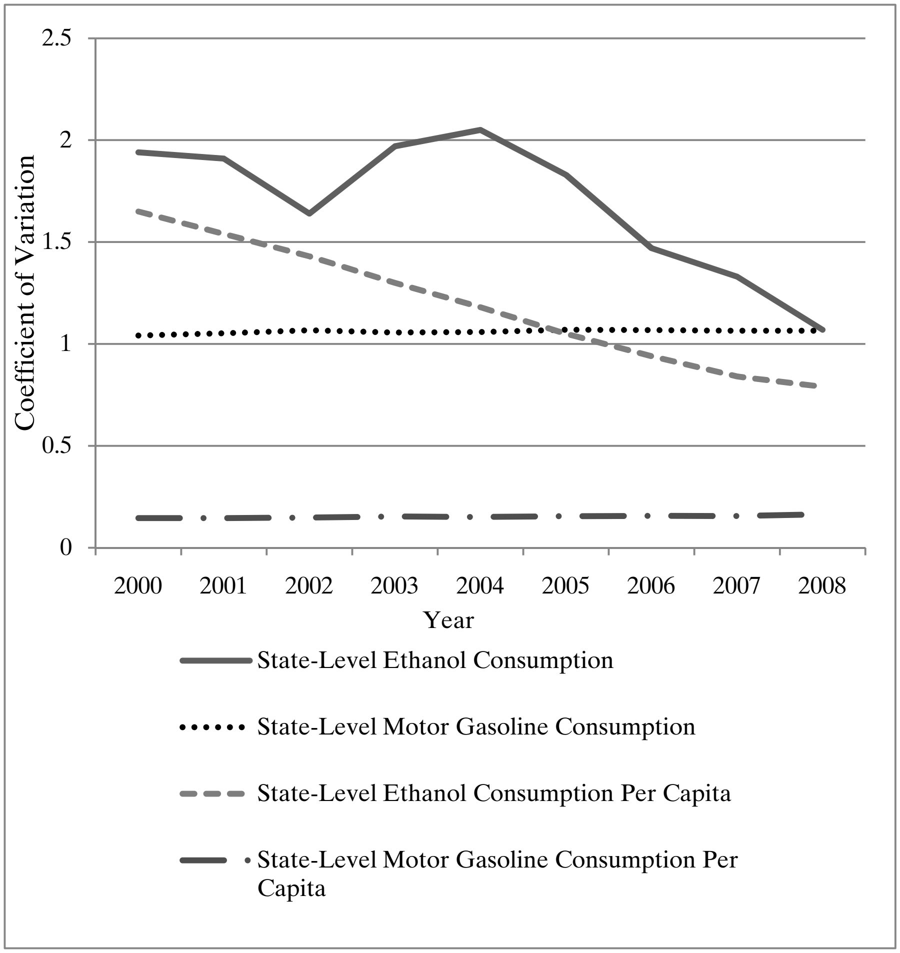
38. U.S. ENERGY INFO. ADMIN., U.S. DEP'T OF ENERGY, PUB. NO. EIA-0214, STATE ENERGY CONSUMPTION ESTIMATES: 1960 THROUGH 2008 (2010), http://www.eia.doe.gov/emeu/states/sep_use/notes/use_print2008.pdf.

39. Note that Table 4 lists only the top five states for ethanol consumption. For lower-ranking states, see *id.*

40. *Id.*

The descriptive statistics derived from the 2008 data are a snapshot of the dispersion of state-level ethanol consumption. Inferring how the dispersion of state-level ethanol consumption has changed over time requires projecting a change in a coefficient of variation over time for both ethanol and motor gasoline consumption, as shown in Figure 1. We can see that the coefficient of variation of ethanol consumption at both state and per capita levels declined over time from 2000 to 2008. On the other hand, the coefficient of variation of motor gasoline consumption remained remarkably stable over time during the same period. Thus, we can infer that there is a tendency for the level of ethanol consumption to become less dispersed across the states over time. As of 2008, however, the dispersion of ethanol consumption remains higher at the per capita level than was the case for motor gasoline, while the coefficients of variation of state-level ethanol and motor gasoline consumption converged to be the same.

FIGURE 1
A CHANGE IN COEFFICIENT OF VARIATION



In general, the statistics indicate that ethanol consumption levels vary from state to state, but the dispersion of ethanol consumption has become smaller over time on both the state and per capita levels. State population influences the total amount of within-state ethanol consumption, so total ethanol consumption does not necessarily capture the typical pattern of individual ethanol consumption. In fact, our data reveal that none of the five largest ethanol consumption states rank among the top five states in terms of ethanol consumption per capita or per vehicle registration. In trying to examine influential factors for ethanol consumption, we must keep in mind that total ethanol consumption and per capita ethanol consumption can diverge and have different implications.

C. Do Regional Economic Conditions Affect State-Level Ethanol Consumption?

Regional economic conditions are likely to influence state-level demand for any good, and ethanol is no exception. This Section focuses on analyzing the relationship between the level of ethanol consumption and macroeconomic indicators. This will allow us to analyze how important regional macroeconomic conditions are to state-level ethanol consumption and per capita ethanol consumption, although we acknowledge that other factors are likely to impact state-level ethanol consumption.

Before carrying out a regression analysis, we will examine simple correlations between state-level ethanol consumption and state-level macroeconomic indicators to obtain a broad picture of the relationship between these variables. Throughout this Section, the unit of analysis is a state and all of the monetary values are deflated using the Consumer Price Index with the year 2000 as the base year.[41]

Figure 2.a depicts the relationship between state-level ethanol consumption and state-level real gross domestic product (GDP) year by year. The figures show no definitive relationship between state-level ethanol consumption and state-level real GDP between 2000 and 2005. A positive relationship between them emerged in 2006, however, and this relationship became stronger in 2008.[42] For purposes of comparison, the relationship between state-level motor gasoline consumption and state-level real GDP is plotted in Figure 2.b. State-level motor gasoline consumption is positively related to state-level real GDP throughout the period between 2000 and 2008. Figure 2.c shows that the relationship between state-level ethanol consumption and population is quite similar to the relationship between state-level ethanol consumption and real GDP. State-level ethanol consumption is plotted against state-level motor gasoline consumption in Figure 2.d.[43] Again, these two variables are positively related to each other after 2005, but such a relationship cannot clearly be observed prior to 2005.

41. For a general discussion of CPI, see *Consumer Price Index Frequently Asked Questions*, BUREAU OF LABOR STATISTICS, U.S. DEP'T OF LABOR, http://www.bls.gov/cpi/cpifaq.htm (last modified June 28, 2010).

42. Before 2005, state-level consumption did not seem to vary with state-level GDP. Most ethanol consumption values were below 500 million gallons, regardless of the state's GDP. *See infra* Figure 2.a.

43. A clear and positive relationship emerges between state-level ethanol and gasoline consumption after 2005, and this is most likely explained by the population growth as it is illustrated *infra* Figure 2.c.

FIGURE 2.A
A CORRELATION BETWEEN ETHANOL CONSUMPTION AND GDP

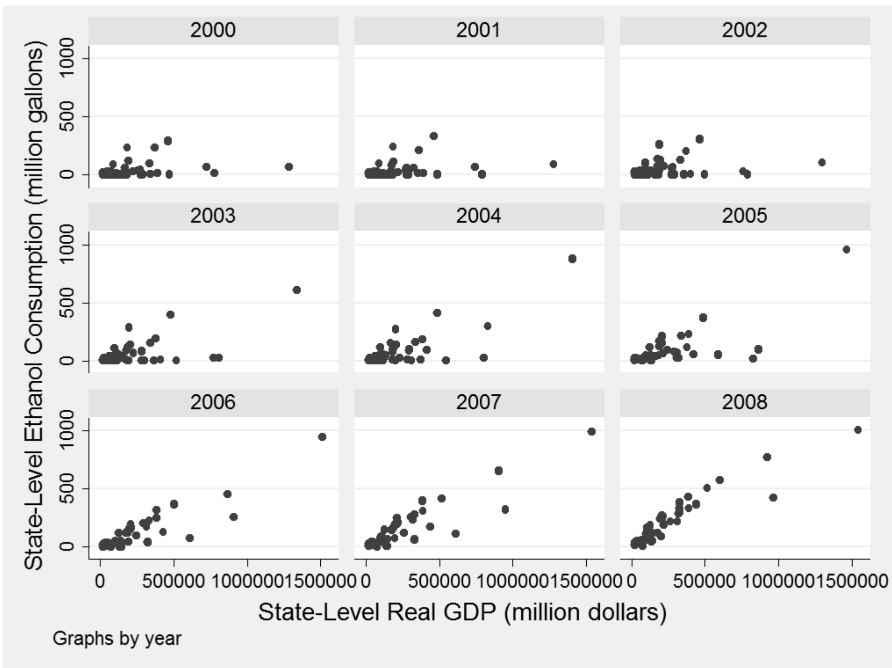


FIGURE 2.B
A CORRELATION BETWEEN GASOLINE CONSUMPTION AND GDP

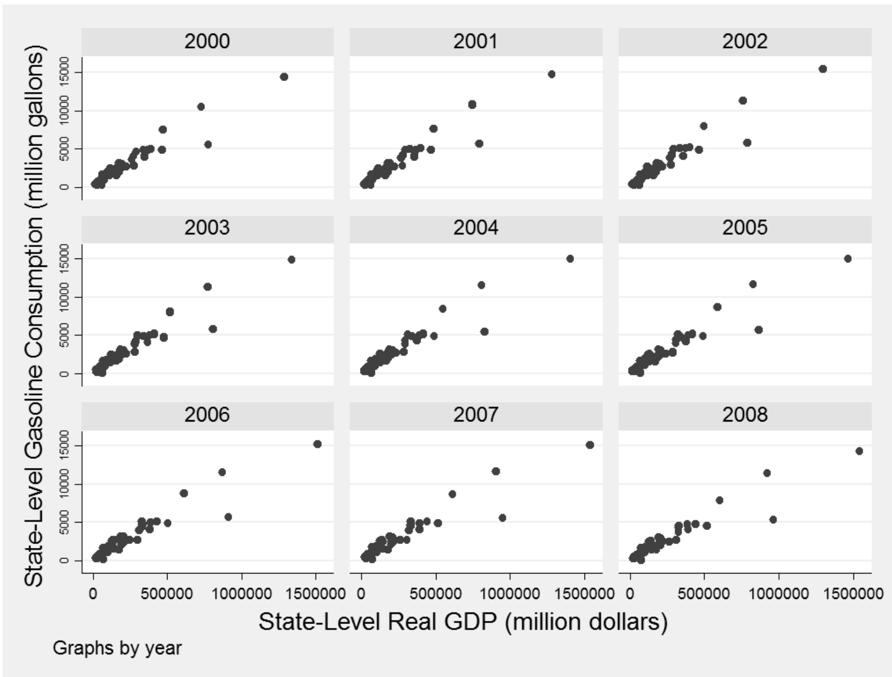


FIGURE 2.C
A CORRELATION BETWEEN ETHANOL CONSUMPTION AND POPULATION

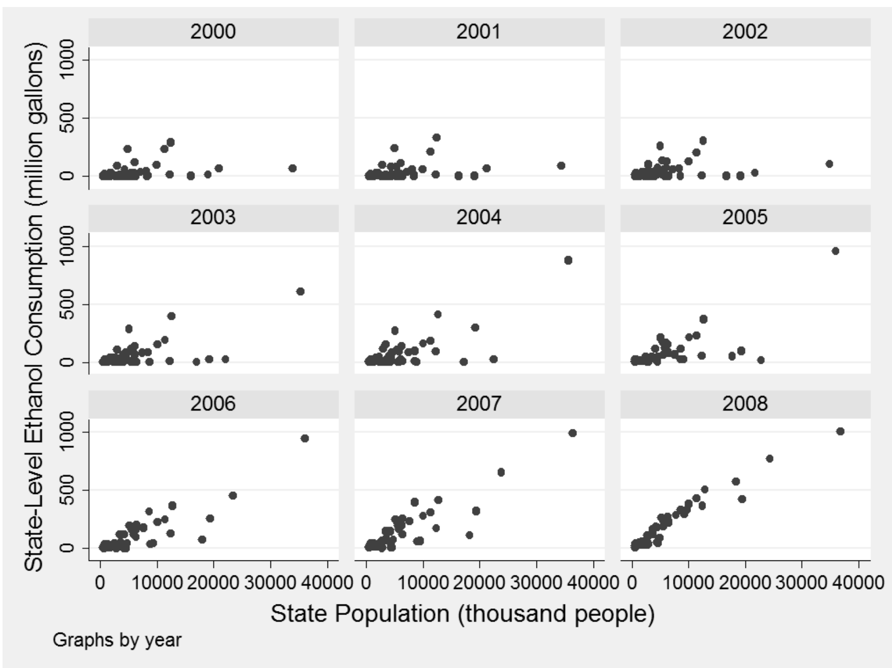
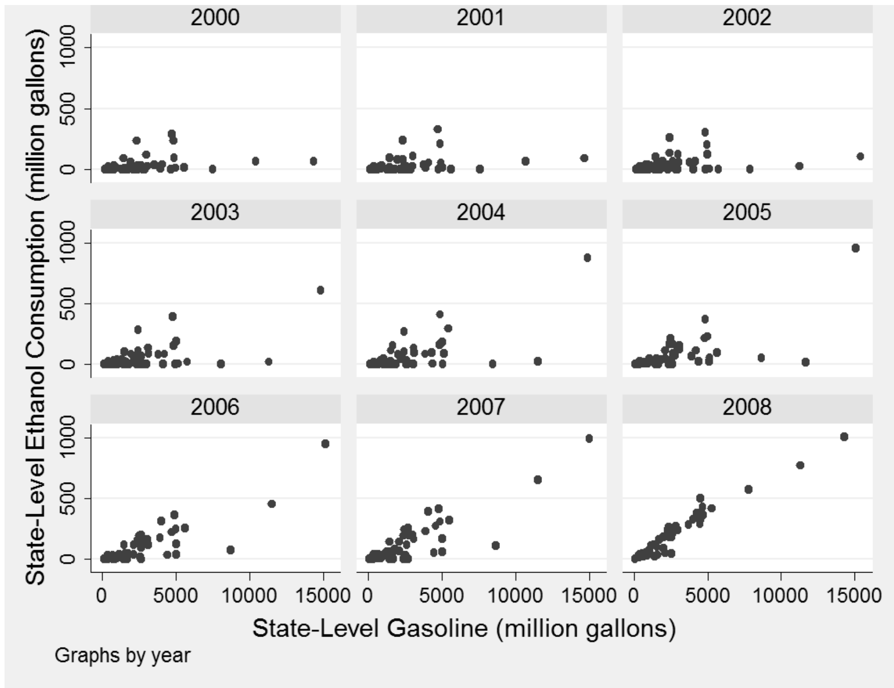


FIGURE 2.D
A CORRELATION BETWEEN ETHANOL CONSUMPTION AND GASOLINE CONSUMPTION



A general observation that can be derived from the simple correlations between state-level ethanol consumption and key regional macroindicators is that the pattern of state-level ethanol consumption appears to have changed around 2005. More specifically, both GDP and population are positively correlated with state-level ethanol consumption after 2005. GDP is also positively related to population, so it is possible that state-level GDP has no impact, or even a negative impact, on state-level ethanol consumption when we control for the population effect. Thus, we need to conduct a regression analysis to generate a scientific inference regarding how state-level ethanol consumption varies in response to different regional economic conditions because we do not control for other variables when we examine a simple correlation.

In our regression analysis in this Section, the dependent variable is one million gallons of state-level total ethanol consumption. Independent variables include GDP, farm income, nonfarm income, population, gasoline consumption, and a dollar value of corn production. State-level GDP is expected to gauge the general economic condition of a given state. We utilize farm income to capture the economic activity level of the agricultural sector of a particular state. Given that most ethanol is currently made from corn, the value of corn production is used to separate its activity from other agricultural activities. State-level population is a proxy for the potential size of ethanol market. We sought to account for year-effects, so year dummies are included in the regression.[44]

Estimation results from both random- and fixed-effects models are reported in Table 5. Because one sign of some of the estimated coefficients differs between the random- and fixed-effects models, we need to examine a statistic for a Hausman test in order to select one of these models. Because P-values for a Hausman test in Table 5 lend support to the fixed-effects model, we focus on interpreting the estimated coefficients from that model. In specification (I), we utilize state-level data for the years 2000 to 2008. We split the sample into two groups, (i) between 2000 and 2005 and (ii) between 2006 and 2008, to examine a change in the pattern of state-level ethanol consumption. Estimation results from each of these two subsamples are reported in specifications (II) and (III), respectively.

According to the fixed-effects model of specification (I), state-level ethanol consumption is positively correlated with state-level real GDP. The estimated coefficient of GDP is 0.002 and it is statistically significant at the 1% significance level.[45] This implies that a change in state-level GDP of one million dollars is associated with an increase in ethanol consumption of 2700 gallons when we control for other variables in the regression. Similarly, state-level ethanol consumption is positively associated with population and farm income, all other things equal. Our regression indicates that state-level ethanol consumption increases by an average of 182 thousand gallons when state population increases by one thousand people, all other factors being equal. In contrast with the simple correlation, state-level motor gasoline consumption is negatively correlated with state-level ethanol consumption when we control for population and other macro variables.

44. A dummy variable is a variable with two values that represent subgroups in the study—in this case, different years. Dummy variables are useful because they enable use of a single regression equation. *See* AJIT C. TAMHANE & DOROTHY D. DUNLOP, STATISTICS AND DATA ANALYSIS: FROM ELEMENTARY TO INTERMEDIATE 419–22 (2000).

45. This level of significance indicates that there is a 1% chance that the positive relationship between state-level GDP and ethanol consumption could have occurred accidentally, based on the sample size. *See id.* at 216–19.

TABLE 5
ESTIMATION RESULTS FOR A RELATIONSHIP BETWEEN ETHANOL CONSUMPTION AND REGIONAL ECONOMIC CONDITIONS

	(I) 2000-2008		(II) 2000-2005		(III) 2006-2008	
	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects
GDP	0.0027***	0.0020***	0.0039***	0.0047***	-0.0001	-0.0030**
	(0.0004)	(0.0005)	(0.0004)	(0.0005)	(0.0005)	(0.0014)
Farm Income	-0.0073	0.0160**	0.0219***	0.0074	0.0012	0.0202
	(0.0079)	(0.0076)	(0.0082)	(0.0077)	(0.0098)	(0.0137)
Non-farm Income	-0.0013**	-0.0003	-0.0032***	-0.0037***	-0.0005	0.0031*
	(0.0006)	(0.0007)	(0.0006)	(0.0008)	(0.0006)	(0.0016)
Population	-0.0234	0.1820***	-0.0165	0.2159***	0.0703***	0.2472***
	(0.0150)	(0.0194)	(0.0188)	(0.0341)	(0.0199)	(0.0704)
Gasoline Consumption	-0.0535***	-0.3236***	-0.0492**	-0.3889***	-0.0653***	-0.2865***
	(0.0187)	(0.0235)	(0.0203)	(0.0319)	(0.0226)	(0.0453)
Value of Corn Production	0.0051	-0.0174***	0.0275**	-0.0034	0.0081	-0.0037
	(0.0069)	(0.0064)	(0.0122)	(0.0210)	(0.0072)	(0.0126)
Number of Observations	459	459	306	306	153	153
P-value for Joint Significance Test	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
P-value for Hausman Test	<0.0001		<0.0001		<0.0001	

Note: (i) The dependent variable is total ethanol consumption (million gallons). Year dummies are included in the regressions, but their coefficients are not reported in Table 5.
(ii) Numbers in round brackets are standard errors.
(iii) ***, **, and * indicate that an estimated coefficient is statistically significant at 1%, 5%, and 10% significance levels, respectively.
(iv) The null hypothesis of the joint significance test is that all coefficients are zero, while the null hypothesis of Hausman test is that random-effects estimator is consistent.
(v) A unit of GDP, farm income, nonfarm income, and a value of corn production is million dollars, while population is measured by a unit of 1000 people. A unit of gasoline consumption is million gallons.

Several matters appear noteworthy in our estimation results derived from the two subsamples. First, state-level ethanol consumption is positively related to population and negatively related to state-level motor gasoline consumption in both specifications (II) and (III). This finding is robust for the periods of observations and indicates that state population is not simply a proxy for motor gasoline consumption. More importantly, because gasoline and ethanol consumption move in opposite directions on the state level, these estimates suggest that ethanol is a substitute for motor gasoline despite the fact that ethanol is mainly used as a gasoline additive.

Second, state-level ethanol is positively related to state-level real GDP before 2005, but is negatively associated between 2006 and 2008. Given that the direction of causality is not established in this regression analysis, we need to interpret this finding with caution and avoid drawing any definitive conclusion. One possibility is that the substitution effect of motor gasoline relative to ethanol is so dominant that state-level ethanol consumption becomes an inferior good. It is also possible that states with large amounts of ethanol consumption correspond to agriculture-based economies whose GDPs are relatively small in size.

Finally, our estimation results from specifications (II) and (III) show that both farm income and the value of corn production have no impact on state-level ethanol consumption in the statistical sense. Because corn is currently the primary feedstock for ethanol production, it is sometimes argued that state-level ethanol consumption is significantly influenced by the activity level of feedstock production. The rationale for this argument is that ethanol is cheaply available in regions where feedstock is abundant. Alternatively, it can be argued that various incentive programs for the promotion of ethanol consumption are politically favored in such states and actually have been implemented there. Our empirical analysis does not support these hypotheses. We stress that this insight may not be applicable to supply-side phenomena, however, because our analysis focuses on the demand side.

In sum, state-level ethanol consumption is positively related to population and negatively related to state-level motor gasoline consumption. There is no statistical relationship between state-level ethanol consumption and agricultural activity indicators. Our estimation also shows that state-level ethanol consumption can decrease with state-level GDP.

D. Do State-Level Incentive Programs Spur Per Capita Ethanol Consumption?

This Section empirically examines the effectiveness of various state-level incentive programs. As discussed in detail in Part II, several states have sought to spur ethanol consumption by implementing different incentive programs. This offers an opportunity to investigate whether these state-level incentives were successful in promoting ethanol consumption and, if so, which policy instrument proved to be the most powerful in achieving the policy goal. The insights from this exercise will be useful both when evaluating current biofuel policies and when formulating future laws.

In this Section, we use per capita ethanol consumption as the variable of primary interest when conducting an empirical analysis. We do so because incentive programs and regulations generally target individual behavior. As was the case in the previous Section, we split the sample into two subgroups—before and after the year 2005—to explore whether per capita ethanol consumption responded to incentives created by state governments in a different manner before and after the year 2005.

Per capita ethanol consumption is regressed on four major policy instruments. The four policy instruments are: (i) a tax reduction for gasohol (E10) relative to motor gasoline (tax differential), (ii) a tax reduction for E85 fuel relative to motor gasoline (E85 tax reduction), (iii) mandatory ethanol blending (mandatory blending), and (iv) alternative fuel vehicle credits/subsidies (AFV credits). We present only the estimation results from the random model because a Hausman test supports the random-effects model over the fixed-effects model.[46]

Estimation results are shown in Table 6, and there is a stark contrast for the results before and after 2005. According to Model (I) of Table 6, the coefficient of all four of the policy instruments is estimated to be positive and statistically significant at least at the 5% significance level. For example, our estimation indicates that per capita ethanol consumption increases by an average of 5.6 gallons per year when the tax rate on gasohol is lower than the tax rate on motor gasoline. An E85 fuel tax reduction also plays a similar role and the magnitude of its effect on per capita ethanol consumption is estimated to be higher than the tax differential between gasohol and gasoline. Similarly, the level of per capita ethanol consumption is higher by 13.5 gallons per year in states that require ethanol blending than in states without a mandatory blending requirement. Our estimate clearly shows that before 2005 several state-level incentives played an important role in promoting per capita ethanol consumption. This trend, however, changed dramatically from 2006 to 2008. The estimated coefficients of all of the four policy instruments are not statistically significant at the conventional significance levels for the subsample from this period of time. In other words, our estimate indicates that the state-level policy instruments of interest are not the decisive factors making a difference in the level of per-capita ethanol consumption across the states during the period between 2006 and 2008.

46. A p-value for a Hausman test is 0.265 for the subsample from the years 2000 to 2005 and 0.834 for the subsample from the years 2006 to 2008. These p-values imply that random-effects estimators are consistent.

TABLE 6
RELATIONSHIPS BETWEEN PER CAPITA ETHANOL CONSUMPTION AND POLICIES

	Model (I)		Model (II)	
	2000 to 2005	2006 to 2008	2002 to 2005	2006 to 2008
Tax Difference Between Gas and Gasohol	5.613** (2.847)	2.623 (6.503)	7.105** (3.188)	-1.689 (6.989)
E85 Tax Credit/ Subsidy	10.381*** (3.714)	5.395 (3.383)	14.522*** (4.710)	3.708 (3.419)
AFV Subsidy	8.230** (4.926)	-2.495 (4.715)	-0.044 (5.602)	-4.257 (4.663)
Mandatory Blending	13.471** (6.126)	2.016 (3.908)	10.936* (6.075)	0.116 (3.945)
No. of E85 Stations			-0.029 (0.070)	0.051* (0.029)
Ethanol Plant Capacity			0.012* (0.006)	0.004 (0.005)
Number of Observations	306	153	204	153
P-value for Joint Significance Test	<0.0001	<0.0001	<0.0001	<0.0001

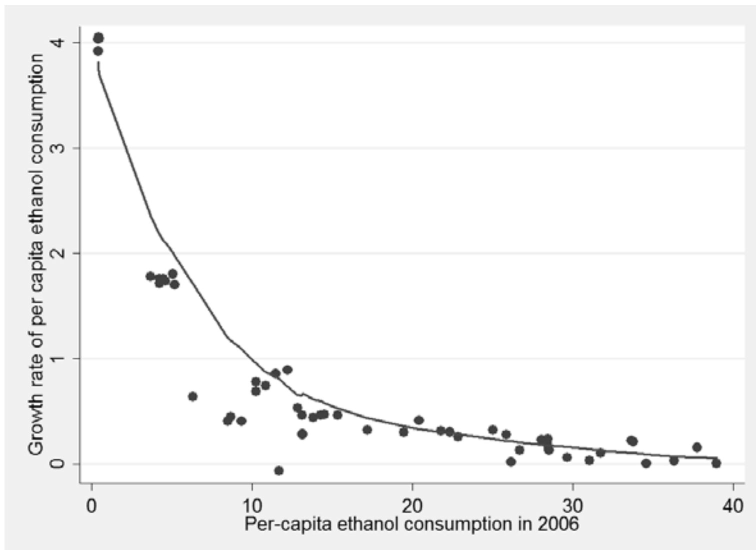
Note: (i) The dependent variable is per capita ethanol consumption (gallons). Year dummies are included in the regressions, but their coefficients are not reported in Table 6.
(ii) Numbers in round brackets are standard errors.
(iii) ***, **, and * indicate that an estimated coefficient is statistically significant at 1%, 5%, and 10% significance levels, respectively.
(iv) The null hypothesis of the joint significance test is that all coefficients are zero.

The estimation results above may be distorted because the possible effects of distribution and supply are not taken into account. In order to investigate this possibility, we included the number of E85 fuel stations within the state and state-level ethanol production capacity in the basic estimating equation, and report the results from this estimation in Model (II) of Table 6. In general, the estimation results from Model (I) survive even after including these variables. As regards the subsample prior to 2005, all of the coefficients of the four policy instruments, with the exception of AFV credits, are still positive and statistically significant at the conventional significance levels. On the other hand, these estimated coefficients do not statistically differ from zero for the subsample from 2006 to 2008. These estimation results therefore suggest that our main finding is unlikely to change qualitatively even if the effects of distribution and supply sides are fully taken into consideration.

We also focused our attention on relationships between per capita ethanol consumption growth and the four policy instruments. The annual growth rate of ethanol consumption of each state, *g*, is computed using the formula, $C_{t+s} = (1 + g)^s C_t$, where C_t is per capita ethanol consumption in year *t*. In other words, *g* is the rate at which per capita ethanol consumption needs to grow in order to reach C_{t+s} in year *t+s*, starting from C_t in year *t*.

Figure 3 shows the growth rates of per capita ethanol consumption between 2006 and 2008 when plotted against 2006 per capita ethanol consumption levels. The growth rates of per capita ethanol consumption become higher when that level is initially smaller. In other words, per capita ethanol consumption tends to grow faster in the states where per capita ethanol is consumed in smaller amounts. If this growth pattern holds firmly, it is expected that per capita ethanol consumption will eventually change (i.e., grow) at the same rate, and that the level of per capita consumption will become uniform across states. Thus, the growth rates of per capita ethanol consumption exhibit the property of "convergence" on at least the state level.

FIGURE 3
A RELATIONSHIP BETWEEN PER CAPITA ETHANOL CONSUMPTION GROWTH AND ITS INITIAL LEVEL



Our interest is in examining whether policy instruments played a significant role in spurring per capita ethanol consumption, or whether the convergence property mentioned above governed the growth rates of per capita ethanol consumption. The top five fastest-growing per capita ethanol consumption states are listed in Tables 7.a and 7.b, which we examined while investigating whether these states implemented all or some of the four policy instruments. To rank states, we use the growth rates of per capita ethanol consumption between 2000 and 2008.[47] We must account for the convergence property, so we divide the sample into two groups according to whether per capita ethanol consumption in a given state in 2000 is below or above 6.1 gallons, which was the average of per capita ethanol consumption in 2000.

47. This choice is mainly made in order to mitigate possible yearly effects. We obtain quantitatively the same results when 2006–2008 growth rates of per capita ethanol consumption are alternatively used.

TABLE 7.A
GROWTH RATES OF PER CAPITA ETHANOL CONSUMPTION
(LARGE CONSUMPTION STATES)

Greater than 6.1 gallons in 2000

Ranking	State	Growth Rate	Tax Difference	E85 Tax Reduction	Mandatory Blending	AFV Credit
1st	Wisconsin	0.27	No	No	No	No
2nd	North Dakota	0.23	No	No	No	No
3nd	Michigan	0.19	No	Yes	No	No
4th	Indiana	0.10	No	No	No	No
5th	Nevada	0.10	No	No	No	No

TABLE 7.B
GROWTH RATES OF PER CAPITA ETHANOL CONSUMPTION
(SMALL CONSUMPTION STATES)

Less than 6.1 gallons in 2000

Ranking	State	Growth Rate	Tax Difference	E85 Tax Reduction	Mandatory Blending	AFV Credit
1st	Florida	1.01	No	No	No	No
2nd	Louisiana	0.92	No	No	Yes	No
3nd	West Virginia	0.89	No	No	No	No
4th	Kentucky	0.68	No	No	No	No
5th	Maryland	0.67	No	No	No	No

Among the fastest per capita ethanol growing states, the ethanol consumption promotion policy was effective in only Louisiana and Michigan from 2000 to 2008. Surprisingly, state-level ethanol consumption promotion policy has had little impact on per capita ethanol consumption growth during the periods examined in this study. The convergence property is so strong that the actual role of the policy instruments appears to be quite minimal. This observation can be confirmed by a regression analysis. Although we do not report the regression results here, an econometric model breaks down in the sense that all of the estimated coefficients of the four policy instruments are jointly insignificant at the conventional significance levels.

In sum, the state-level incentives we examined were not powerful tools for spurring per capita ethanol consumption from 2000 to 2008, particularly after 2005. The level of per capita ethanol consumption indeed responded to state-level incentives before 2005, but this relationship cannot be found after 2005. There is no systematic association between the growth rates of per capita ethanol consumption and state-level incentives between 2000 and 2008. The growth rate of per capita ethanol consumption was higher when the initial level of per capita ethanol consumption was lower.

IV. DISCUSSION

Our empirical analyses revealed that a national market for biofuels is likely to emerge if the current trend of ethanol consumption continues. We also documented that, while large-scale biofuel consumption will be mandated under the federal RFS, some state governments are likely to continue their own incentive programs. Our empirical analyses showed that state-level incentive programs became ineffective for the purpose of incentivizing ethanol consumption after 2005, the year the original RFS was signed. We did not conduct an in-depth analysis of the relationship between the RFS and the effectiveness of state-level incentive programs, so we do not claim that the RFS caused state-level incentive programs to be ineffective. Instead, we regard our empirical results as a reminder that federal- and state-level policies can complement or substitute for each another. Some policies can work against each other at different levels. This point is logically apparent, but it is often obscured when it comes to policy discussions.

By way of illustration of our argument, federal- and state-level mandatory demand policies are perfectly substitutable. This implies that state-level mandatory demand policy is likely to be nullified when federal-level mandatory demand policy is effective, and vice versa. The federal-level mandatory demand policy can complement the state-level subsidy of purchases of alternative fuel vehicles. Mandatory demand under the RFS can be ineffective when tax incentives at the state level are so strong that biofuels consumption exceeds the volumetric requirement set by the RFS. These are a few examples that illustrate the need to understand which state-level policies can complement or substitute for federal-level policies, particularly the RFS.

Our empirical analyses also showed that the law of convergence—ethanol consumption grows at a faster rate when the level of ethanol consumption (i.e., the initial baseline) is smaller—is currently the dominant force behind state-level ethanol consumption growth. This empirical result offers two important insights regarding biofuel consumption promotion policies at the federal level. First, at the developmental stage of a national market for biofuels, it may initially make sense to focus on states with low levels of biofuel consumption in order to increase aggregate U.S. biofuel consumption, all other factors being equal. Instead of applying a biofuel promotion policy uniformly to all fifty states, U.S. aggregate biofuel consumption might be able to reach a targeted amount in a shorter period of time and/or do so in a less costly manner by accelerating the convergence process of biofuel consumption among states that exhibit low levels of biofuel consumption. Second, the law of convergence predicts that ethanol consumption growth eventually will slow down for all states if economic conditions do not change. In other words, some economic forces are necessary to alter the steady state of biofuel consumption. Technological progress for biofuel production can help to break such stagnation and serve as an engine for biofuel consumption growth. Although this study does not directly investigate the effects of supply and research and development on biofuel consumption, our empirical examination of demand-side factors also points to the importance of technological progress in the biofuel production sector.

We also documented that state-level ethanol consumption becomes less dispersed over time, and that state-incentive programs became ineffective after 2005. One possible interpretation of this empirical result is that those states that saturated their own state markets, or hit a blending wall, start supplying ethanol to other states. We examined this possibility by looking at the relationship between ethanol blending percentages and out-of-state supplies. If this mechanism is indeed in operation, we expect the ethanol blending percentage to remain stable over time, and the out-of-state supplies to rise. Figure 4 projects the evolution of the ratio of ethanol consumption to motor gasoline consumption for the top five states in ethanol production capacity (Illinois, Iowa, Minnesota, Nebraska, and South Dakota), whereas the evolution of out-of-state supply—ethanol production capacity less ethanol consumption—is projected in Figure 5. During the period between 2002 and 2008, the ratio of ethanol consumption to motor gasoline consumption was unstable. For example, Iowa's ethanol-to-gasoline ratio dropped to 2.1% in 2005 from 6.8% in 2004. Despite this drop, Iowa's out-of-state supply increased during the same period. The overall picture seen in Figures 4 and 5 is that out-of-state supply increased steadily between 2002 and 2008, but the ethanol-to-gasoline ratio of each state moved up and down during the same periods of time. This observation does not lend a definitive support to the hypothesis that saturation of the state market or a blending wall played a major role in reducing the dispersion of state-level ethanol consumption over time or in nullifying the effects of some state incentive programs.

FIGURE 4
RATIO OF ETHANOL TO MOTOR GASOLINE CONSUMPTION

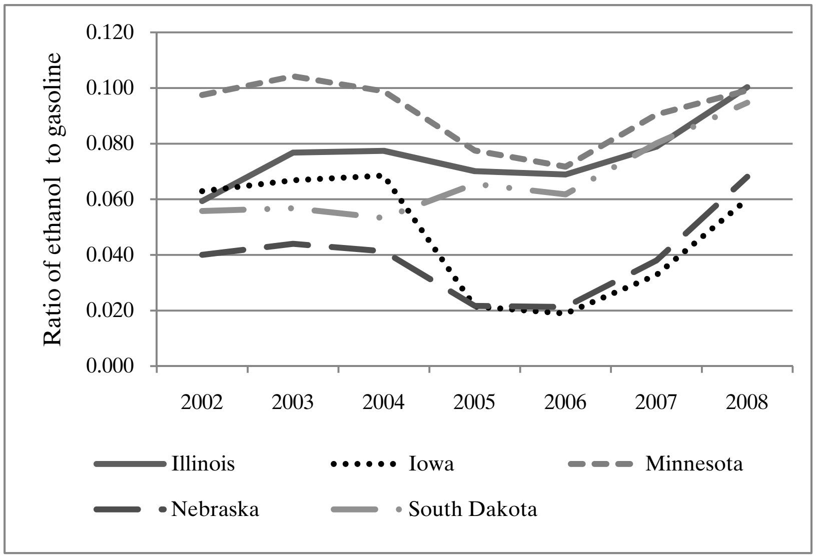
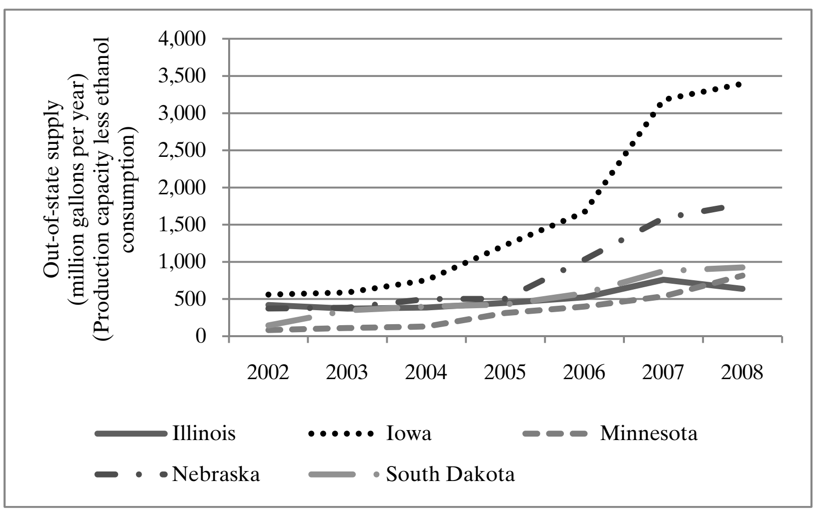


FIGURE 5
OUT-OF-STATE SUPPLY



V. CONCLUSION

This study examined ethanol consumption data in order to understand factors that influence state-level ethanol consumption patterns. Our examination of this data revealed a number of striking ethanol consumption patterns. First, the dispersion of state-level ethanol consumption has become increasingly smaller over time. This suggests that ethanol consumption will become less dependent on regional economic conditions if this trend continues; stated differently, we expect a national market for ethanol to emerge soon. Second, state-level incentive programs worked well to raise the level of per capita ethanol consumption before 2005, but these incentive programs appeared to have played a minor role after 2005. Finally, our empirical examination of per capita ethanol consumption confirms the convergence property. Irrespective of state-level incentive programs, the growth rate of per capita ethanol consumption increases when the initial level of per capita ethanol consumption is lower.

This study has limitations. We therefore should be cautious when interpreting some of the empirical results presented above. The empirical analyses of this study involved abstracting distribution- and supply-side factors in order to focus on demand-side incentives. Many state governments have already implemented distribution- and supply-oriented incentive programs to help make ethanol a viable alternative fuel for consumers. It is unlikely that such incentive programs will fail to influence the demand side in some manner. These incentive programs will probably complement demand-side incentive programs. Although this topic is both interesting and important, it is beyond the scope of this study, and a thorough investigation of this topic is a subject for future research. This study did not examine the effects of pricing on ethanol consumption. One reason is that reliable ethanol price data is not available at the state level. A more important reason is rooted in the objective of this study. The objective of this study was not to estimate a demand curve per se, but instead to identify factors that shift the demand curve or the market equilibrium demand. Given that our reduced form estimations satisfy this purpose sufficiently, we did not apply structural model estimations in this study. Another possible critique of this study might be that this study emphasized cross-sectional aspects more than time-series aspects. We sought to investigate possible time-series effects in a simple manner, so we tried several specifications by including lagged ethanol consumption in the basic estimating equation. The basic findings of this study still survive even after accounting for possible time-series effects, although we do not report the estimation results in this Article.

In spite of the limitations discussed above, this study contributes significantly to advancing our understanding of the roles of state incentive programs. Our scientific way of examining the ethanol consumption data provides policy makers with useful guidance for assessing how ethanol consumption responds to incentives in practice. This will allow them to evaluate alternative incentive programs that may be under consideration and formulate and implement fine-tuned policies. This study also gives consumers and ethanol business leaders an opportunity to understand the costs and benefits of a particular incentive program. Informed individuals can judge the merits and demerits of policies and regulations with greater confidence and accuracy. We thus strongly believe that this study not only satisfies academic interests but also meets practical needs for several issues related to ethanol consumption.

APPENDIX

[Department of Energy] *Ethanol Incentives and Laws*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/ethanol/incentives_laws.html (last visited Jan. 29, 2011).

[Alaska] ALASKA STAT. § 43.40.010(a)(4)(A) (2008); *Alaska Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/AK/ETH (last visited Jan. 29, 2011).

[Florida] FLA. STAT. § 526.201–526.207 (Supp. 2010); *Florida Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/FL/ETH (last visited Jan. 29, 2011).

[Georgia] GA. CODE. ANN. § 48-7-40.16(b) (2009); *Georgia Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/GA/ETH (last visited Jan. 29, 2011).

[Hawaii] HAW. REV. STAT. ANN. § 486J-10 (LexisNexis 2009); *Hawaii Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/HI/ETH (last visited Jan. 29, 2011).

[Illinois] 35 ILL. COMP. STAT. 105/3-10, 105/3-44 (2009); 415 ILL. COMP. STAT. 120/30; *Illinois Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/IL/ETH (last visited Jan. 29, 2011).

[Kansas] KAN. STAT. ANN. §§ 79-3401, 79-3490, 79-32,201, 79-34,141 (2008); *Kansas Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/KS/ETH (last visited Jan. 29, 2011).

[Louisiana] LA. REV. STAT. ANN. §§ 3:4674(C)(1), 47:6035 (Supp. 2010); *Louisiana Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/LA/ETH (last visited Jan. 29, 2011).

[Michigan] MICH. COMP. LAWS ANN. § 207.1008 (West 2010); *Michigan Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/MI/ETH (last visited Jan. 29, 2011).

[Minnesota] MINN. STAT. ANN. § 239.791 (West 2010); *Minnesota Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/MN/ETH (last visited Jan. 29, 2011).

[Missouri] MO. REV. STAT. § 414.255 (Supp. 2010); *Missouri Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/MO/ETH (last visited Jan. 29, 2011).

[Montana] MONT. CODE ANN. §§ 15-30-2320, 82-15-121 (2009); *Montana Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/MT/ETH (last visited Jan. 29, 2011).

[Nebraska] *Dollar and Energy Savings Loans*, NEB. ENERGY OFFICE, http://www.neo.ne.gov/loan/ (last visited Jan. 29, 2011); *Nebraska Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/NE/ETH (last visited Jan. 29, 2011).

[New York] N.Y. TAX LAW § 1115 (McKinney 2008); *New York Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/NY/ETH (last visited Jan. 29, 2011).

[Oklahoma] OKLA. STAT. tit. 68, § 500.10-1 (Supp. 2009); OKLA. DEP'T OF COMMERCE, ALTERNATIVE FUEL VEHICLE LOAN PROGRAM (AFV), *available at* http://www.okcommerce.gov/Libraries/Documents/Alternative-Fuel-Vehicles-Loan_2063.doc (last visited Jan. 29, 2011); *Oklahoma Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/OK/ETH (last visited Jan. 29, 2011).

[Oregon] OR. REV. STAT. § 646.913 (2009); *Oregon Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/OR/ETH (last visited Jan. 29, 2011).

[Texas] *AirCheck Texas–Drive a Clean Machine*, HOUS.-GALVESTON AREA COUNCIL, http://www.h-gac.com/human-services/airchecktexas/default.aspx (last visited Jan. 29, 2011); *Texas Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/TX/ETH (last visited Jan. 29, 2011).

[Washington] WASH. REV. CODE § 19.112.120 (West 2007); *Washington Incentives and Laws for Ethanol*, U.S. DEP'T OF ENERGY, http://www.afdc.energy.gov/afdc/progs/ind_state_laws.php/WA/ETH (last visited Jan. 29, 2011).