Yet More with Market Equilibrium Models

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WiNDC Short Course – 20 July 2021

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Class Agenda for Today

- Supply and demand – recap of basic concepts
- Integrable demand and supply functions
- Incidence and burden
- The global market for coal
- Globalization, trade and climate policy: the problem of *carbon dioxide leakage*

Outline

- Recap
- Integrable functions
- Incidence and burden
- Global market for coal
- A model of carbon leakage

Demand and Consumer Surplus

- *Demand* is the function that gives the number of units purchased as a function of the price.
- The difference between your *willingness to pay* and the amount you pay is known as *consumer surplus*: the dollar value of consumer willingness to pay less the market value of the sales.
- *Consumer surplus* is represented in a demand graph by the area under the demand curve and above the consumer price.
- Many, but not all, goods have the feature of *diminishing marginal value* – the value of the last unit consumed declines as the number consumed rises.
- Demand is usually graphed with *price on the vertical axis* and *quantity on the horizontal axis*.
- Demand refers to the entire curve, while quantity demanded is a point on the curve.
- The *marginal value curve* is the *inverse demand function*.

Demand and Consumer Surplus (cont.)

- An *increase in demand* is represented by a movement of the entire curve to the northeast (up and to the right), which represents an increase in the marginal value v (movement up) for any given unit, or an increase in the number of units demanded for any given price (movement to the right). Similarly, the reverse movement represents a decrease in demand.
- Demand may affected by the price of related goods, but we will address the representation of *complements* and *substitutes* in subsequent lectures.
- In partial equilibrium models, aggregate consumer surplus may be *infinite*, but in policy analysis we are concerned with the change in consumer surplus which is nearly always finite and well defined.

Supply and Profit

- The supply curve gives the number of units as a function of the price that will be supplied for sale to the market.
- Price equals marginal cost is an implication of profit maximization in a competitive market; the supplier sells all the units whose cost is less than price and doesn't sell the units whose cost exceeds price.
- The supply curve is the inverse function of marginal cost. Graphed with the quantity supplied on the horizontal axis and price on the vertical axis, the supply curve is the marginal cost curve, with marginal cost on the vertical axis.

Supply and Profit (cont.)

- Profit is given by the difference of the price and marginal cost.
- An increase in supply refers to either more units available at a given price or a lower price for the supply of the same number of units. Thus, an increase in supply is graphically represented by a curve that is lower or to the right, or both – that is, to the southeast. A decrease in supply is the reverse case, a shift to the northwest.
- Anything that increases costs of production will tend to increase marginal cost and thus reduce the supply.

Market Demand and Supply

- The market demand gives the quantity purchased by all the market participants – the sum of the individual demands – for each price. This is sometimes called a horizontal sum because the summation is over the quantities for each price.
- The market supply is the horizontal (quantity) sum of all the individual supply curves.

Equilibrium

- The quantity supplied of a good or service exceeding the quantity demanded is called a surplus.
- If the quantity demanded exceeds the quantity supplied, a shortage exists.
- The equilibrium price is the price in which the quantity supplied equals the quantity demanded.
- The equilibrium of supply and demand maximizes the total gains from trade.

Changes in Demand and Supply

- An increase in the demand increases both the price and quantity traded.
- A decrease in demand implies a fall in both the price and the quantity traded.
- An increase in the supply decreases the price and increases the quantity traded.
- A decrease in the supply increases the price and decreases the quantity traded.

Changes in Demand and Supply (cont.)

- People react less to temporary changes than to permanent changes. People rationally continue to operate obsolete devices until their useful life is over, even when they wouldn't buy an exact copy of that device, an effect called hysteresis.
- Short-run and long-run effects represent a theme of economics, with the major conclusion that substitution doesn't occur instantaneously, which leads to predictable patterns of prices and quantities over time.

Elasticity

- The elasticity of demand is the percentage decrease in quantity that results from a small percentage increase in price, which is generally denoted with the Greek letter epsilon, ϵ.
- The percentage change of total revenue resulting from a 1% change in price is one minus the elasticity of demand.
- An elasticity of demand that is less than one is defined as an inelastic demand. In this case, increasing price increases total revenue.
- A price increase will decrease total revenue when the elasticity of demand is greater than one, which is defined as an elastic demand.
- The case of elasticity equal to one is called unitary elasticity, and total revenue is unchanged by a small price change.

Elasticity (cont)

- If demand takes the form $x(p) = ap^{-\epsilon}$, then demand has *constant elasticity* and the demand function is *isoelastic* with elasticity is equal to ϵ.
- The elasticity of supply is defined as the percentage increase in quantity supplied resulting from a small percentage increase in price.
- If supply takes the form $s(p) = ap^{\eta}$, then supply has constant elasticity, and the elasticity is equal to η.

Competitive Market Assumptions

- A market is typically competitive when there are many producers and consumers.
- Assume are presently no taxes, and there is a stable equilibrium price. At this price, the elasticity of demand is ϵ and the elasticity of supply is η.
- Assume that market demand and market supply curves are both linear.

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Calibrated Linear Demand and Supply

- Demand (specific tax t)

$$D(p) = \underbrace{\bar{q}}_{\text{Benchmark quantity}} \times \left(1 - \underbrace{|\epsilon|}_{\frac{\%\Delta q}{\%\Delta p^D}} \times \left(\underbrace{\frac{p+t}{\bar{p}} - 1}_{\%\Delta p^D}\right)\right)$$

- Supply (specific tax t)

$$S(p) = \underbrace{\bar{q}}_{\text{Benchmark quantity}} \times \left(1 + \underbrace{\eta}_{\frac{\%\Delta q}{\%\Delta p^S}} \times \left(\underbrace{\frac{p-t}{\bar{p}} - 1}_{\%\Delta p^S}\right)\right)$$

Calibrated Linear Demand and Supply

- Demand (ad-valorem tax τ)

$$D(p) = \underbrace{\bar{q}}_{\text{Benchmark quantity}} \times \left(1 - \underbrace{|\epsilon|}_{\frac{\%\Delta q}{\%\Delta p^D}} \times \left(\underbrace{\frac{p(1+\tau)}{\bar{p}} - 1}_{\%\Delta p^D}\right)\right)$$

- Supply (proportional tax ν)

$$S(p) = \underbrace{\bar{q}}_{\text{Benchmark quantity}} \times \left(1 + \underbrace{\eta}_{\frac{\%\Delta q}{\%\Delta p^S}} \times \left(\underbrace{\frac{p(1-\nu)}{\bar{p}} - 1}_{\%\Delta p^S}\right)\right)$$

N.B. In this specification, τ is defined on a *net basis* while ν is defined on a *gross basis*.

Calibrated Isoelastic Demand and Supply

- Demand

$$D(p) = \bar{q}\left(\frac{p+t}{\bar{p}}\right)^{-\epsilon}$$

- Supply

$$S(p) = \bar{q}\left(\frac{p-t}{\bar{p}}\right)^{\eta}$$

Integrable Demand

Consider the trivial optimization problem:

$$\max f(q)$$

s.t.

$$q = \bar{q}$$

Let the Lagrange multiplier on the constraint be p. The first order condition for q is then:

$$\frac{\mathrm{df(q)}}{\mathrm{dq}} = p$$

Integrable Demand (cont.)

For what functional form $f(q)$ is this first order condition equivalent to the following?

A linear demand function

$$p = \bar{p}\left[1 - \frac{1}{\epsilon}\left(\frac{q}{\bar{q}} - 1\right)\right]$$

An isoelastic demand function

$$p = \bar{p}\left(\frac{q}{\bar{q}}\right)^{-1/\epsilon}$$

Integrable Demand (cont.)

Representing $p = g(q)$ implies

$$f(q) = \int g(q)\mathrm{dq}$$

In the case of the linear demand function we have

$$f(q) = \bar{p}q\left[1 - \frac{1}{\epsilon}\left(\frac{q}{2\bar{q}} - 1\right)\right]$$

In the case of the isoelastic demand function we have

$$f(q) = \frac{\bar{p}q}{1 - 1/\epsilon}\left(\frac{q}{\bar{q}}\right)^{-1/\epsilon}$$

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Definitions of incidence.

Definition: *tax incidence on consumers* is the amount by which the buyer price, P_D, rises over the non-tax equilibrium price, P^*, ; the tax incidence on producers is the amount by which the seller price, P_S, falls below P^*.

The total tax wedge equals the sum of the tax incidence on the buyer and on the seller. The shares depend on the elasticities of demand and supply. The tax incidence is larger in the less elastic side of the market.

Incidence

If the gross of tax price increases from the reference price much more than producer price declines, then the consumer bears the burden of the tax. If the gross of tax price increases much less than producer price declines, then the consumer bears the burden of the tax.

We can evaluate how the tax burden is allocated solely on the basis of the elasticities of supply and demand.

Incidence (cont.)

As expected, the producer price declines with the tax.

- Extreme case 1: supply is perfectly inelastic ($\eta = 0$) and the demand elasticity is not zero ($\epsilon < 0$): the producer price declines one for one with the tax.
- Extreme case 2: supply is elastic ($\eta > 0$) and demand is perfectly inelastic ($\epsilon = 0$): then the producer price is unaffected by the tax.

The new equilibrium (cont.)

The consumer price is given by:

$$p^* + t = p_0 + \frac{t}{1 - \epsilon/\eta}$$

The price impact on consumers likewise depends on demand and supply elasticities. When demand is less elastic than supply, then the demand price is more responsive to the tax increase. If supply is less elastic, then the demand price is unaffected.

Back of the envelope calculation of tax incidence

Changes in the demand price (P_D) and the supply price (P_S) are inversely proportional to the ratio of the demand and supply elasticities:

$$\frac{\Delta P_D}{\Delta P_S} \approx \frac{\eta}{\epsilon}$$

where:

- η is the elasticity of supply,
- ϵ is the elasticity of demand

Justification for the back-of the envelope calculation

Consider a small tax applied in a market initial in equilibrium with quantity Q^* and price P^*:

$$\epsilon = \frac{\Delta Q_D / Q^*}{\Delta P_D / P^*} \Rightarrow \frac{\Delta Q_D}{Q^*} = \frac{\Delta P_D}{P^*}\epsilon$$

$$\eta = \frac{\Delta Q_S / Q^*}{\Delta P_S / P^*} \Rightarrow \frac{\Delta Q_S}{Q^*} = \frac{\Delta P_S}{P^*}\eta$$

If the market remains in equilibrium, $\Delta Q_D = \Delta Q_S$, and

$$\frac{\Delta P_D}{\Delta P_S} = \frac{\eta}{\epsilon}$$

Textbook exercise: tax incidence and burden

- The environment minister decides to levy an excise tax on coal sales at rate t.
- This means that if a seller receives p^*, the buyer pays $p^* + t$.
- The demand price is therefore *gross of tax* and the producer price is *net of tax*.
- When a tax is applied, the quantity transacted declines as the consumer price (gross of tax) rises and the producer price (net of tax) declines.

A Textbook Exercise (cont.)

Given:

- Market equilibrium price equals \$1 per unit.
- Quantity currently bought and sold equals 100 units.
- Price elasticity of supply equals 2.
- Price elasticity of demand equals 0.5.

The Problem

- A sales tax equal to 1 is applied to all transactions.
- Find the tax incidence.
- Find the resulting tax revenue.
- Find the change in consumer surplus.
- Find the change in producer surplus.

Solve the model... one equation in one unknown

$$D(p) = S(p)$$

or

$$100\left(1 - 0.5\left(p + 1 - 1\right)\right) = 100\left(1 + 2(p - 1)\right)$$

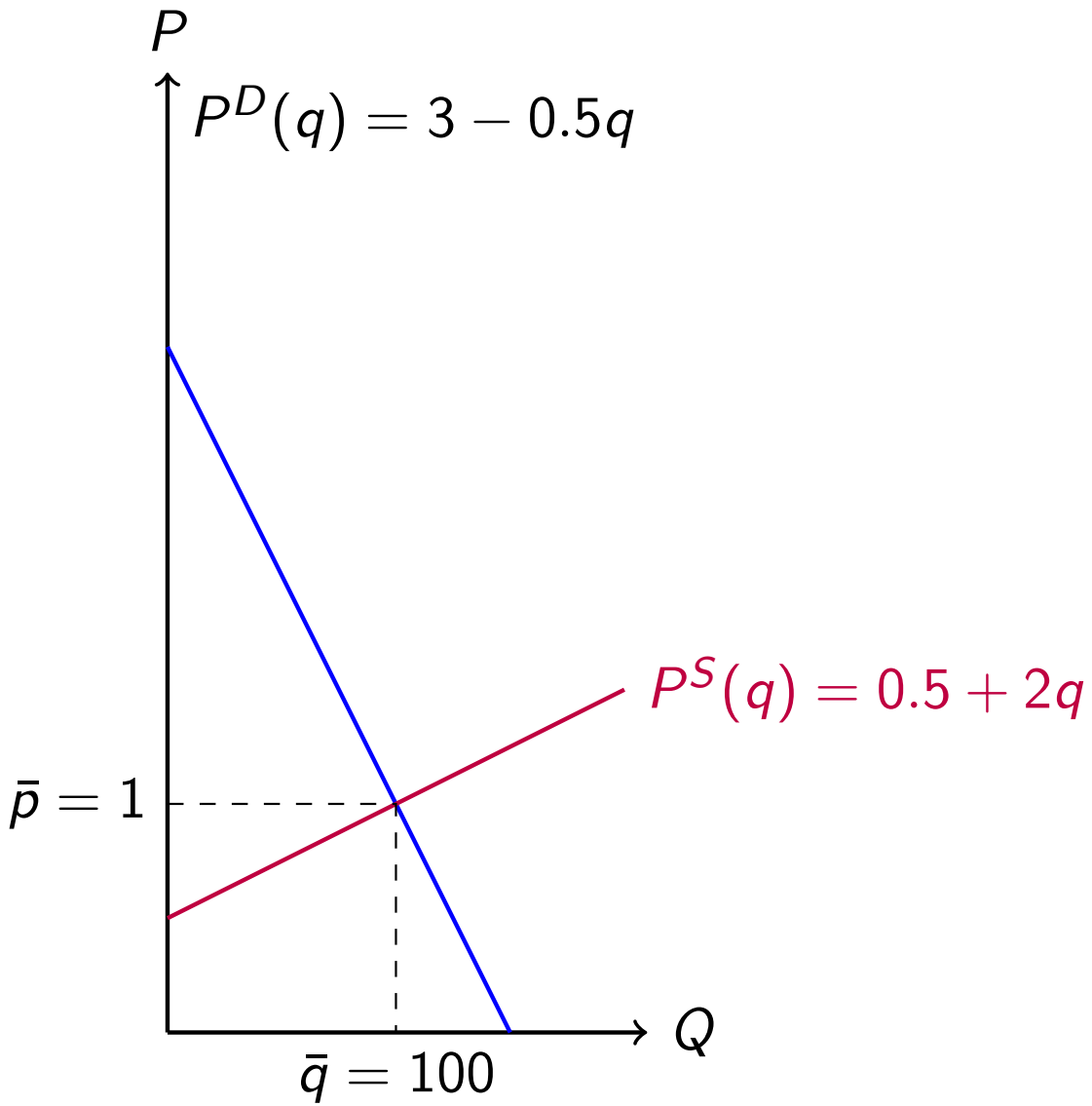
$$-0.5(p + 1 - 1) = 2(p - 1)$$

$$2.5p = 2 \quad \Rightarrow \quad p^* = 0.8$$

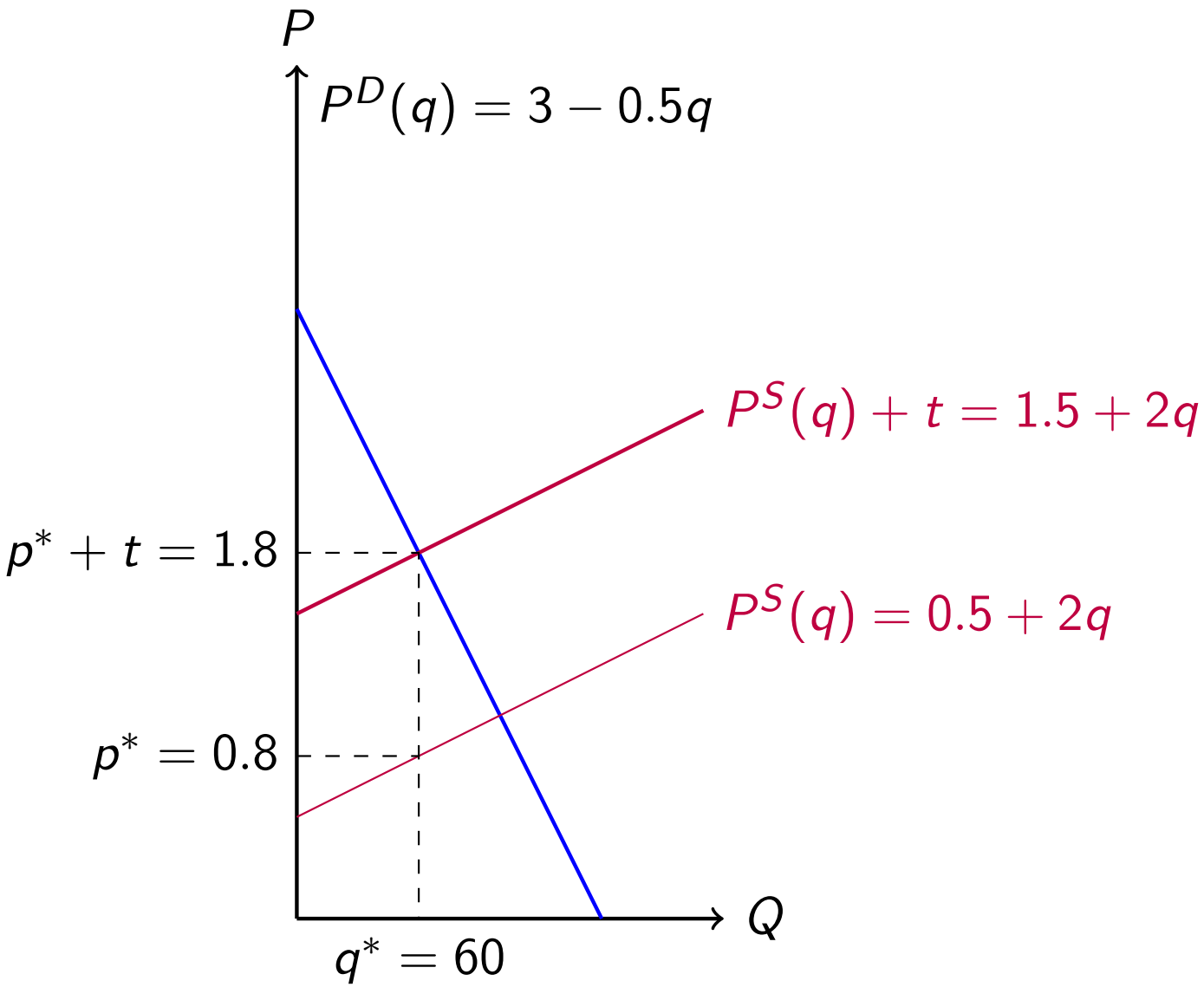
Solution:

- Supply price $= p^* = 0.8$ (incidence $= -0.2$).
- Demand price $= p^* + t = 0.8 + 1 = 1.8$ (incidence $= +0.8$).
- Equilibrium quantity: $q^* = 100 \times (1 - 2 \times 0.2) = 60$
- Tax revenue $T = t \times q^* = 60$
- Change in consumer suplus
  $= -(60 \times 0.8 + 0.5 \times 40 \times 0.8) = -(48 + 16) = -64$
- Change in producer surplus
  $= -(60 \times 0.2 + 0.5 \times 40 \times 0.2 = -(12 + 4) = -16$

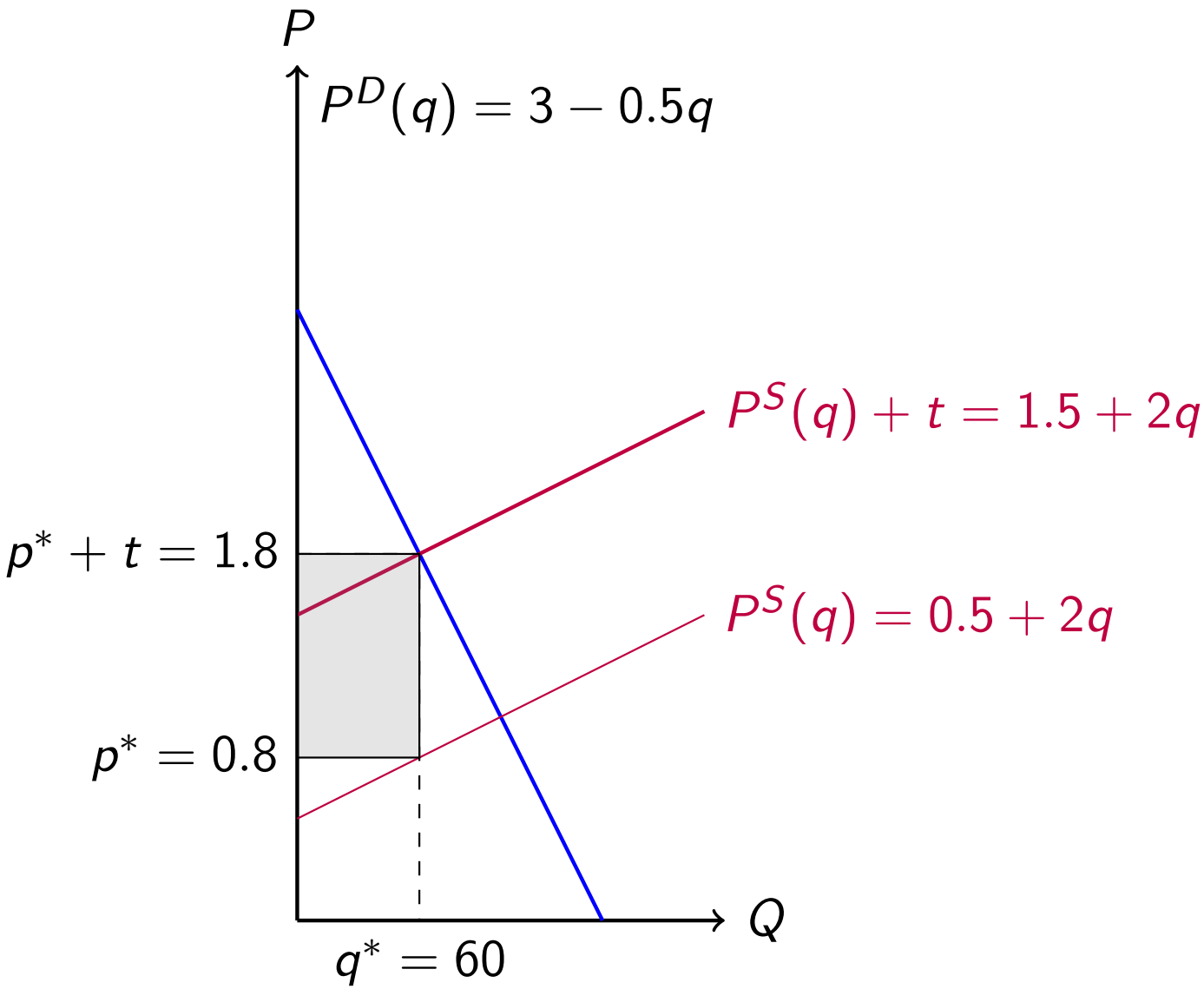
Benchmark Equilibrium



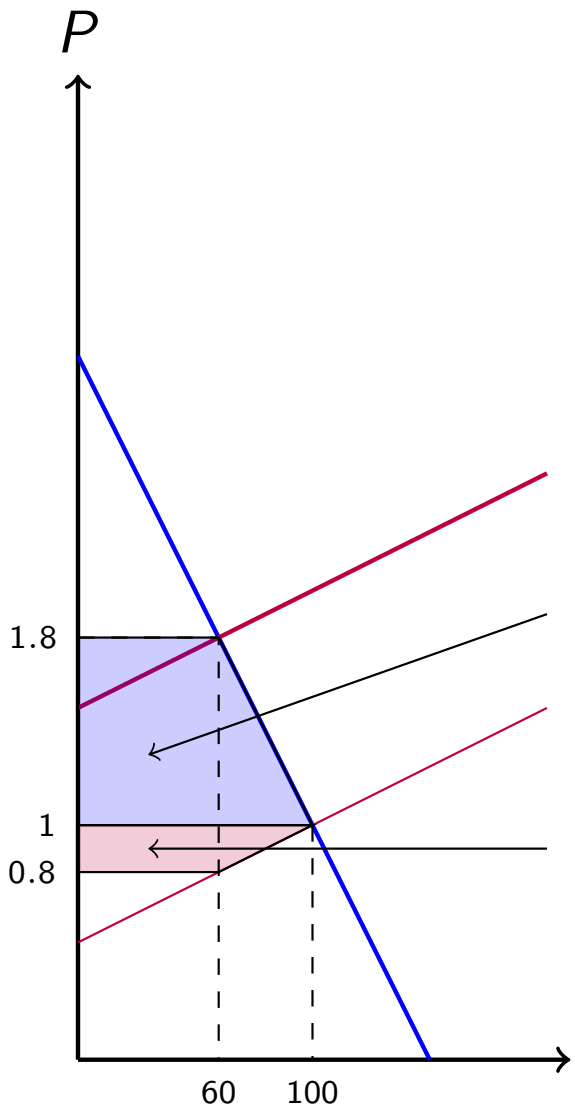
Tax-Ridden Equilibrium



Tax Revenue



Loss in Consumer and Producer Surplus



$$\Delta CS = -(60 \times 0.8 + 0.5 \times 40 \times 0.8)$$
$$= -(48 + 16)$$
$$= -64$$

$$\Delta PS = -(60 \times 0.2 + 0.5 \times 40 \times 0.2)$$
$$= -(12 + 4)$$
$$= -16$$

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Economic Models

Models play an important role in the formulation of trade policy. The Marshallian market equilibrium model for competitive markets in which supply and demand are jointly determined along with price. We want to begin with a graphical framework the implications of government policy interventions in this model, interventions such as taxes, quotas, tariffs and subsidies.

A Policy Issue

When Australia mitigates carbon emissions, this drives down the price of coal and increases incentives to coal exports. If coal exports increase, this can induced increased emissions in China.

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The purpose of this computational exercise is to assess the global environment effectiveness of subglobal policy measures. More to the point, to what extent does international trade *vitiate* the effectiveness of climate policy measures undertaken in a subset of regions.

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A Modeling Exercise

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6. Evaluate the *global leakage rate*:

$$\ell = \frac{\%\text{ increase in coal use in non-coalition states}}{\%\text{ decrease in coal use in coalition states}}$$

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8. Remember that *The most interesting answer to any question in economics is:* **It depends.**

Coal Market Data: 1

http://www.worldcoal.org/

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Coal in the Modern World

Coal is a vital global energy source - not only does coal provide electricity, it is also an essential fuel for steel and cement production, and other industrial activities. Technologies are continuously being developed to increase the ways in which coal can be utilised, to improve the efficiency of coal, and to meet environmental challenges - including carbon capture and storage technology.

What's New

- 22 Jan - New Issue of Ecoal Now Available
  12 Jan - NMA Launches New Safety Initiative
- 25 Nov - Industry tells Governments to Raise Game on CCS

Coal Info

- Geology
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- Climate Change
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- Carbon Capture & Storage
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Coal Market Data: 2

Coal Market Data: 3

Coal Market Data: 4

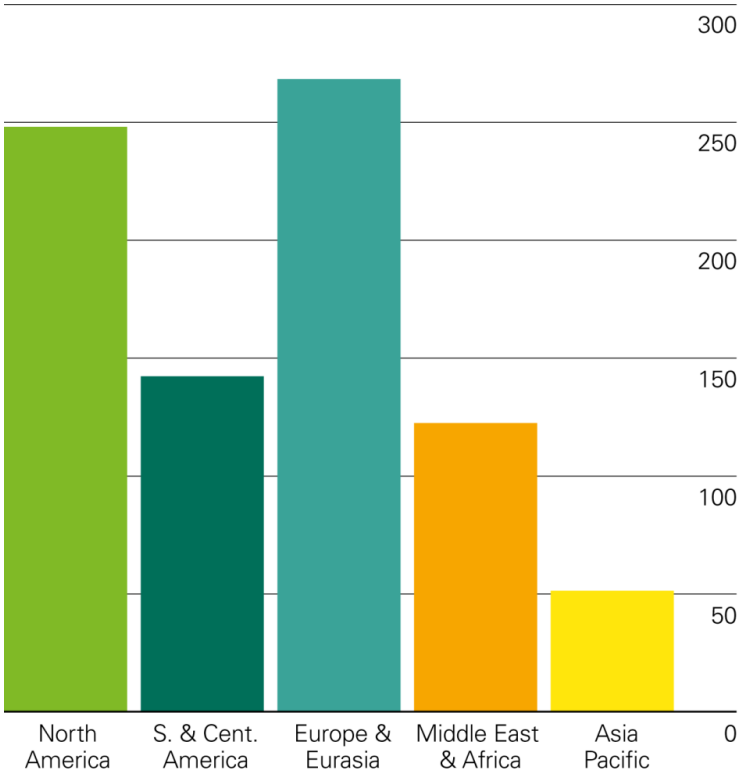
Coal Market Data: 5

Coal

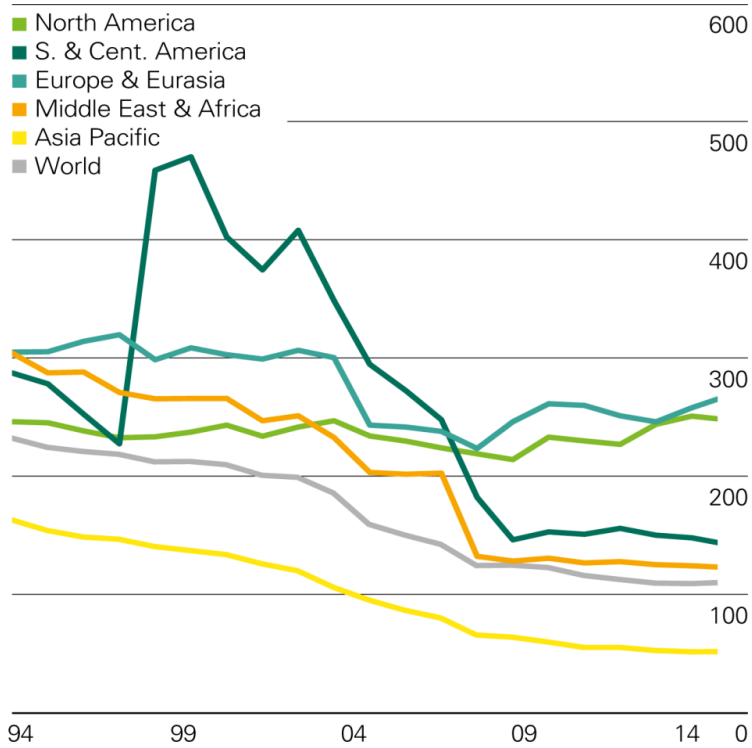
Coal reserves-to-production (R/P) ratios

Years

2014 by region



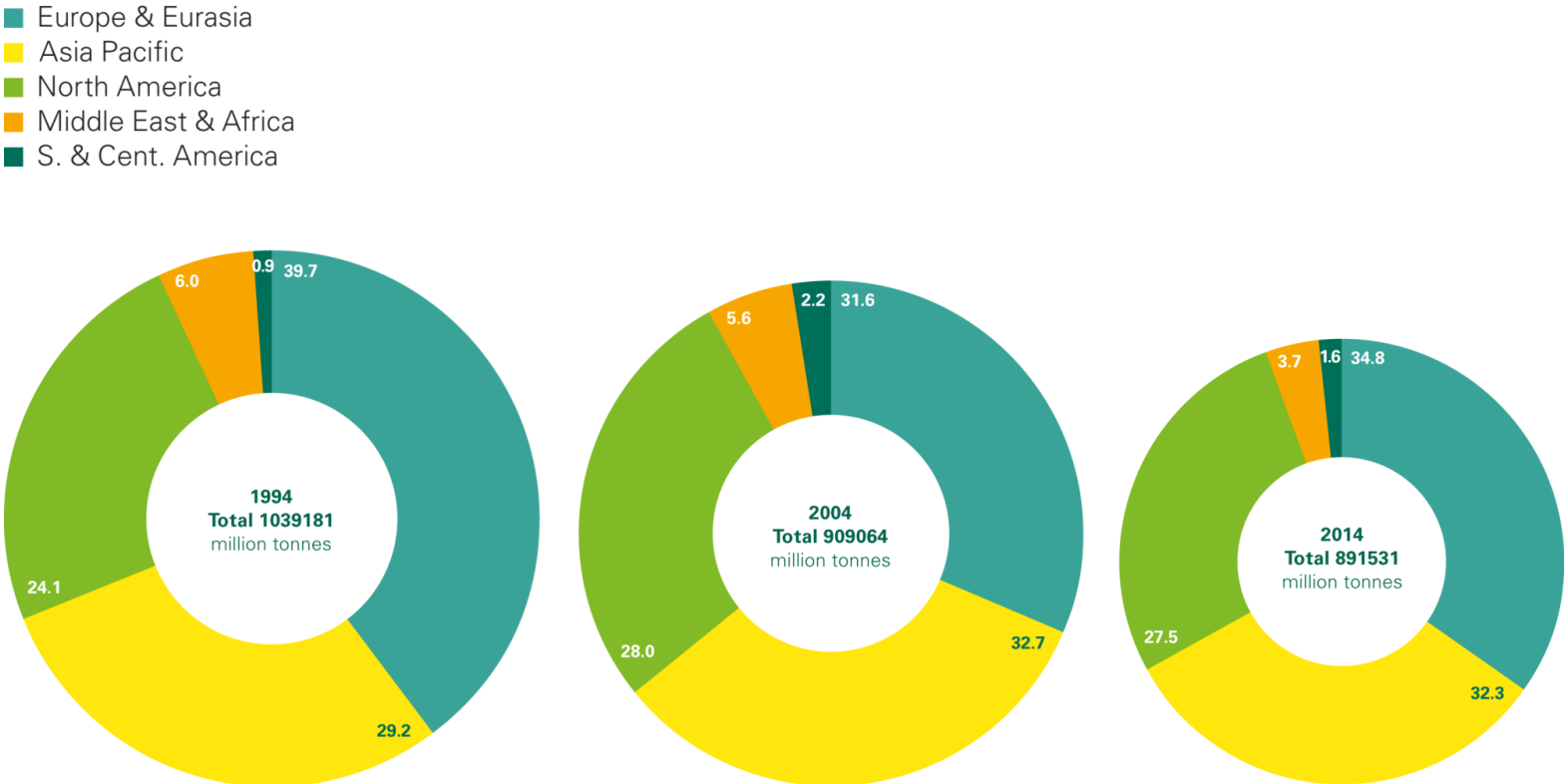
History



BP Statistical Review of World Energy 2015

Distribution of proved coal reserves: 1994, 2004 and 2014

Percentage

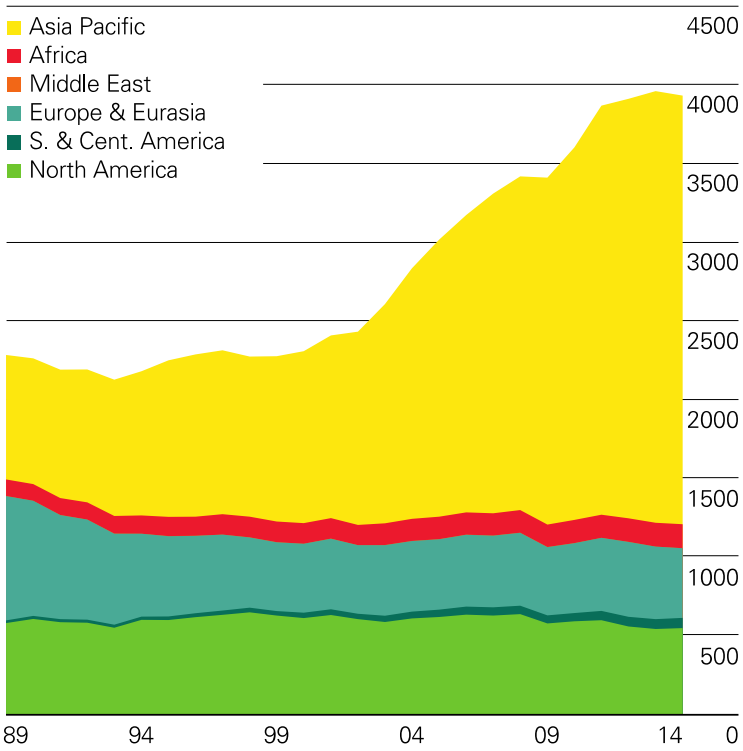


Source: World Energy Resources 2013 Survey, World Energy Council.

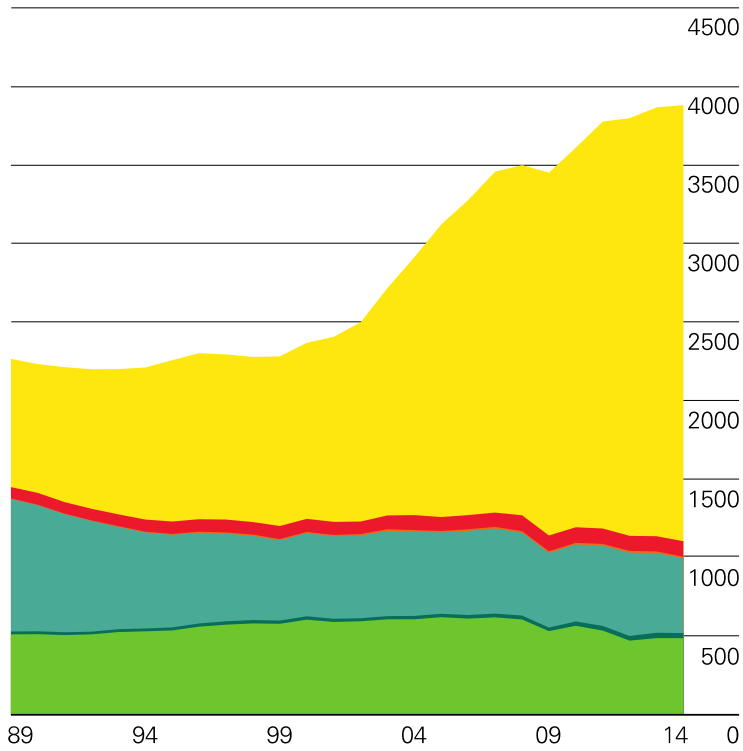
Coal production/consumption by region

Million tonnes oil equivalent

Production by region

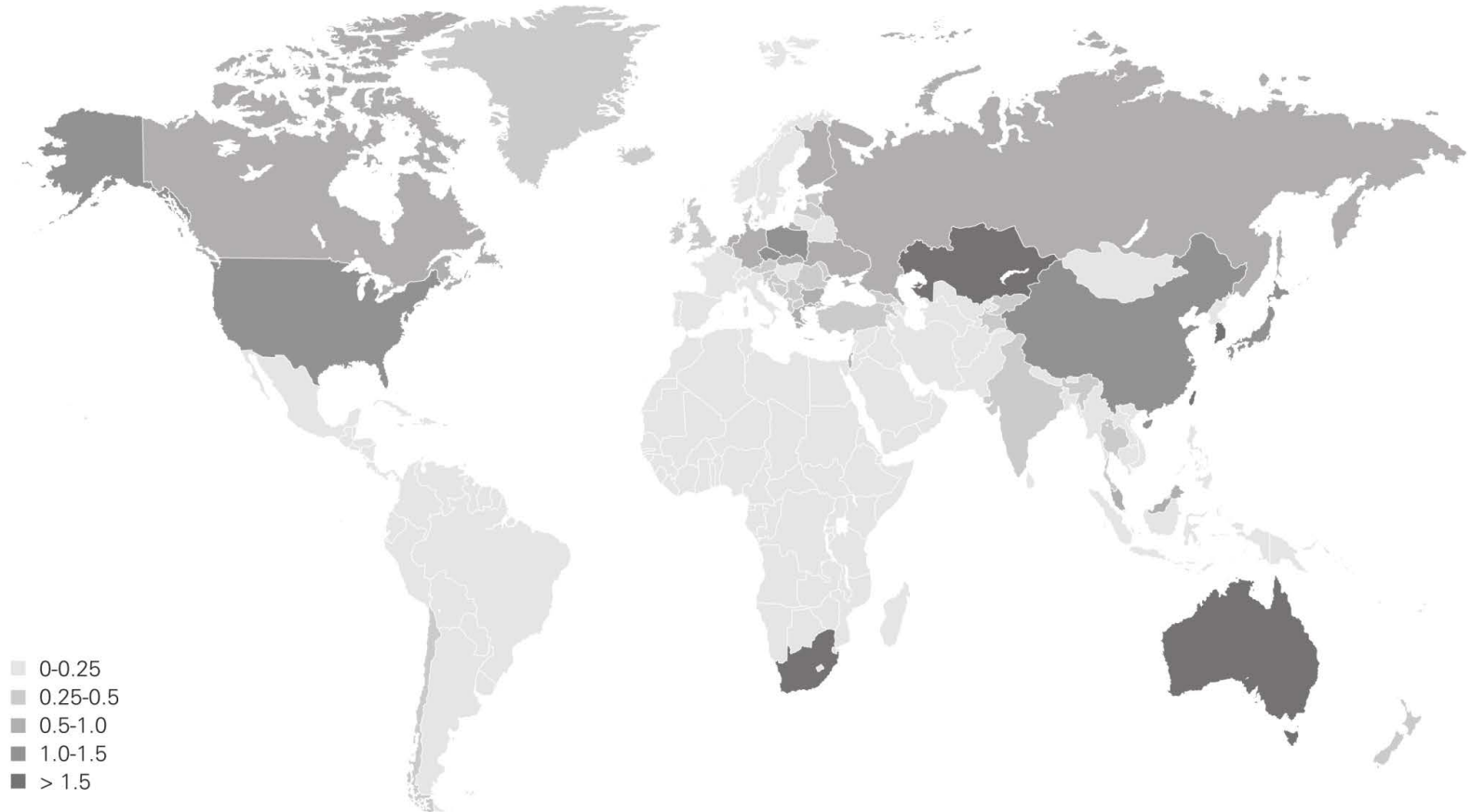


Consumption by region



Coal consumption per capita 2014

Tonnes oil equivalent



BP Statistical Review of World Energy 2015

US Coal Use: Northern States

Table 26. U.S. Coal Consumption by End Use Sector, Census Division, and State, 2013 and 2012

(thousand short tons)

Census Division and State	2013				2012				Total		
	Electric Power[1]	Other Industrial	Coke	Commercial and Institutional	Electric Power[1]	Other Industrial	Coke	Commercial and Institutional	2013	2012	Percent Change
New England	**2,791**	**87**	**-**	**-**	**1,920**	**81**	**-**	**-**	**2,878**	**2,001**	**43.8**
Connecticut	419	-	-	-	415	-	-	-	419	415	0.9
Maine	38	27	-	-	32	19	-	-	66	51	28.4
Massachusetts	1,718	59	-	-	954	61	-	-	1,778	1,015	75.1
New Hampshire	616	-	-	-	520	-	-	-	616	520	18.5
Middle Atlantic	**45,234**	**2,323**	**6,401**	**119**	**44,838**	**2,440**	**5,341**	**131**	**54,077**	**52,750**	**2.5**
New Jersey	1,017	-	-	-	1,007	-	-	-	1,017	1,007	1.0
New York	2,225	664	152	-	2,228	748	161	-	3,041	3,137	-3.1
Pennsylvania	41,992	1,659	6,249	119	41,602	1,692	5,180	131	50,019	48,606	2.9
East North Central	**194,616**	**9,220**	**11,948**	**517**	**181,275**	**8,906**	**12,125**	**578**	**216,301**	**202,884**	**6.6**
Illinois	51,996	3,118	1,566	132	48,509	3,165	1,588	129	56,812	53,390	6.4
Indiana	46,671	2,156	5,364	133	46,696	1,974	5,704	197	54,324	54,571	-0.5
Michigan	31,653	1,256	1,333	73	29,669	1,051	1,240	90	34,315	32,050	7.1
Ohio	40,623	1,288	3,685	146	37,119	1,327	3,593	131	45,742	42,170	8.5
Wisconsin	23,674	1,403	-	32	19,283	1,388	-	30	25,109	20,701	21.3
West North Central	**136,626**	**13,337**	**-**	**403**	**133,859**	**13,373**	**-**	**382**	**150,366**	**147,615**	**1.9**
Iowa	19,517	3,433	-	210	20,747	3,345	-	213	23,160	24,305	-4.7
Kansas	18,915	85	-	-	17,759	88	-	-	19,000	17,847	6.5
Minnesota	13,765	1,270	-	6	13,384	1,131	-	3	15,041	14,518	3.6
Missouri	44,463	1,085	-	99	42,340	1,014	-	90	45,647	43,444	5.1
Nebraska	15,829	1,124	-	-	14,884	1,038	-	-	16,953	15,922	6.5
North Dakota	22,289	6,133	-	88	22,795	6,555	-	73	28,510	29,423	-3.1

US Coal Use: Southern States

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	Electric Power[1]	Other Industrial	Coke	Commercial and Institutional	Electric Power[1]	Other Industrial	Coke	Commercial and Institutional	2013	2012	Percent Change
South Atlantic	**118,142**	**5,516**	**1,790**	**199**	**116,981**	**5,862**	**1,934**	**203**	**125,647**	**124,979**	**0.5**
Delaware	708	-	-	-	682	-	-	-	708	682	3.9
District of Columbia	-	-	-	-	-	-	-	3	-	3	-95.0
Florida	20,905	575	-	-	19,932	502	-	-	21,480	20,433	5.1
Georgia	20,633	731	-	5	20,836	853	-	7	21,370	21,696	-1.5
Maryland	6,789	705	-	9	6,930	906	-	19	7,503	7,855	-4.5
North Carolina	19,170	663	-	134	20,876	661	-	125	19,967	21,662	-7.8
South Carolina	9,973	504	-	-	11,658	506	-	-	10,477	12,164	-13.9
Virginia	9,869	1,333	1,039	51	6,497	1,437	1,038	49	12,292	9,020	36.3
West Virginia	30,093	1,006	752	-	29,571	998	896	-	31,851	31,464	1.2
East South Central	**86,428**	**5,180**	**1,334**	**80**	**84,705**	**5,007**	**1,352**	**94**	**93,022**	**91,158**	**2.0**
Alabama	24,400	1,500	1,334	-	23,020	1,322	1,352	-	27,235	25,695	6.0
Kentucky	39,475	1,073	-	15	38,978	1,118	-	31	40,563	40,128	1.1
Mississippi	5,867	123	-	-	5,240	113	-	-	5,989	5,354	11.9
Tennessee	16,686	2,484	-	65	17,466	2,453	-	63	19,235	19,982	-3.7
West South Central	**153,834**	**1,997**	**-**	**9**	**147,392**	**1,917**	**-**	**10**	**155,840**	**149,319**	**4.4**
Arkansas	18,766	215	-	-	17,023	217	-	-	18,980	17,240	10.1
Louisiana	13,787	146	-	-	14,746	147	-	-	13,934	14,893	-6.4
Oklahoma	18,794	634	-	-	18,317	606	-	-	19,428	18,923	2.7
Texas	102,487	1,002	-	9	97,305	947	-	10	103,498	98,263	5.3

US Coal Use: Western States

Table 26. U.S. Coal Consumption by End Use Sector, Census Division, and State, 2013 and 2012

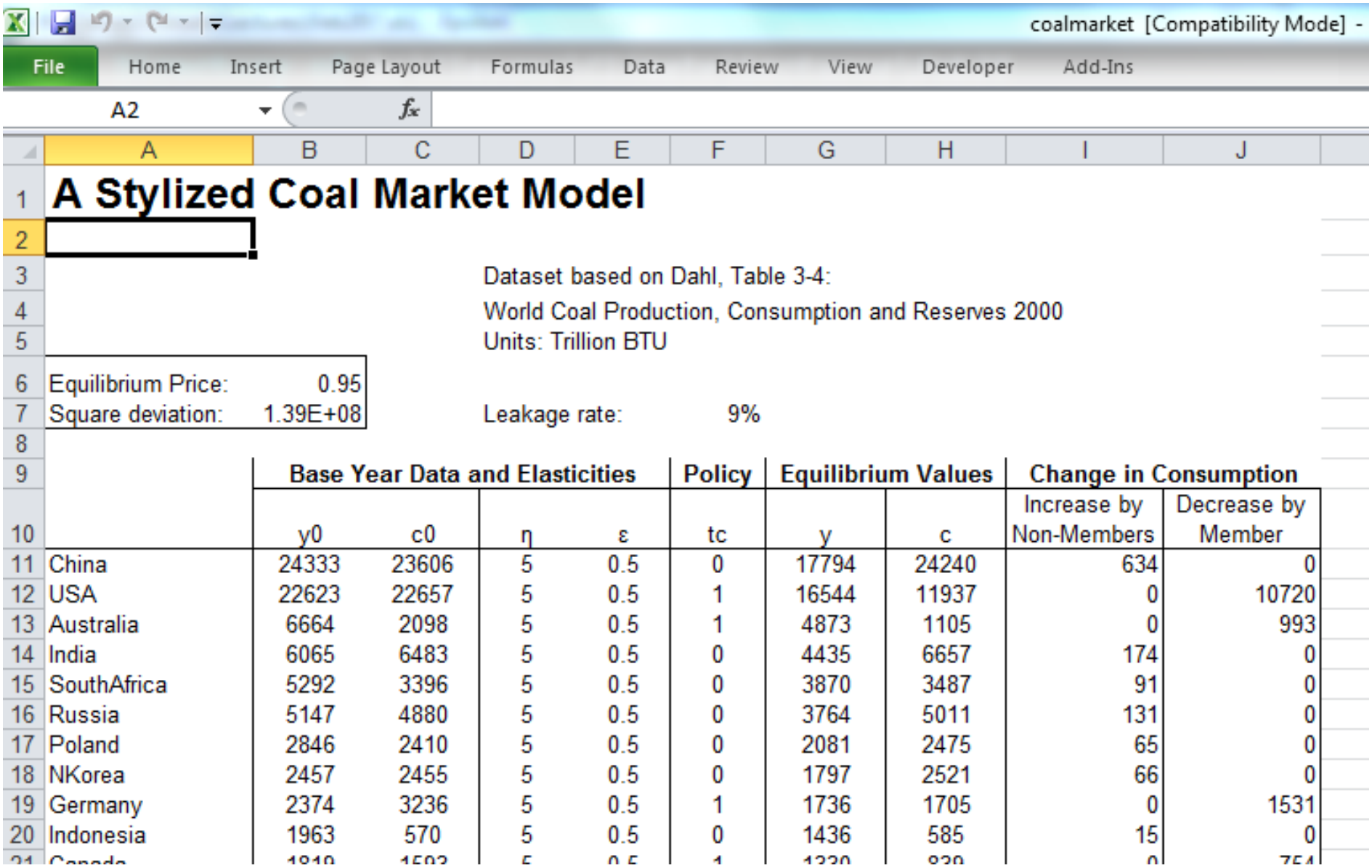
(thousand short tons)

Census Division and State	2013 Electric Power[1]	2013 Other Industrial	2013 Coke	2013 Commercial and Institutional	2012 Electric Power[1]	2012 Other Industrial	2012 Coke	2012 Commercial and Institutional	Total 2013	Total 2012	Percent Change
Mountain	**112,329**	**3,759**	**-**	**38**	**106,776**	**3,694**	**-**	**44**	**116,126**	**110,513**	**5.1**
Arizona	23,298	181	-	-	21,461	418	-	-	23,479	21,879	7.3
Colorado	18,822	339	-	5	19,199	281	-	10	19,166	19,490	-1.7
Idaho	-	360	-	4	-	248	-	5	364	253	43.5
Montana	9,562	262	-	2	9,057	238	-	5	9,826	9,300	5.7
Nevada	2,933	334	-	-	2,258	299	-	-	3,267	2,556	27.8
New Mexico	14,270	51	-	-	14,452	42	-	-	14,321	14,494	-1.2
Utah	15,529	645	-	-	14,084	588	-	-	16,173	14,671	10.2
Wyoming	27,916	1,588	-	27	26,265	1,581	-	24	29,531	27,870	6.0
Pacific	**7,963**	**1,636**	**-**	**585**	**5,805**	**1,558**	**-**	**603**	**10,184**	**7,966**	**27.8**
Alaska	400	1	-	585	427	1	-	603	986	1,031	-4.4
California	259	1,383	-	-	539	1,323	-	-	1,643	1,863	-11.8
Hawaii	692	61	-	-	753	50	-	-	753	803	-6.3
Oregon	2,183	85	-	-	1,583	75	-	-	2,268	1,658	36.8

Implementation

The model is built in Excel. The "model" consists of an Excel worksheet with regional data. Regions are largely countries but also includes some country aggregates such as "OtherEEur" (other Eastern Europe), "OtherCSA" (other Central and South America), etc. The model inputs include base year supply and demand, elasticities of supply and demand, and consumption tax rates. The model outputs include equilibrium supply and demand for each of the regions along with an international price index.

The Worksheet



coalmarket [Compatibility Mode] -

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A2

A Stylized Coal Market Model

Dataset based on Dahl, Table 3-4:
World Coal Production, Consumption and Reserves 2000
Units: Trillion BTU

Equilibrium Price:	0.95
Square deviation:	1.39E+08

Leakage rate: 9%

	Base Year Data and Elasticities				Policy	Equilibrium Values		Change in Consumption	
	y0	c0	η	ε	tc	y	c	Increase by Non-Members	Decrease by Member
China	24333	23606	5	0.5	0	17794	24240	634	0
USA	22623	22657	5	0.5	1	16544	11937	0	10720
Australia	6664	2098	5	0.5	1	4873	1105	0	993
India	6065	6483	5	0.5	0	4435	6657	174	0
SouthAfrica	5292	3396	5	0.5	0	3870	3487	91	0
Russia	5147	4880	5	0.5	0	3764	5011	131	0
Poland	2846	2410	5	0.5	0	2081	2475	65	0
NKorea	2457	2455	5	0.5	0	1797	2521	66	0
Germany	2374	3236	5	0.5	1	1736	1705	0	1531
Indonesia	1963	570	5	0.5	0	1436	585	15	0

Solving the Model