Econ 230A: Public Economics
Lecture: Externalities

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These lecture notes are partially based on lectures developed by Raj Chetty and Day Manoli. Many thanks to them for their generosity.
Outline

- Externalities
  1. What are externalities?
  2. Correcting Externalities
  3. Prices. vs. Quantities
  4. Optimal 2nd Best Taxation with Externalities
  5. Empirical Applications
1. What are externalities?

- An externality arises whenever the utility or production possibility of an agent depends *directly* on the actions of another agent (firm or individual).
- Directly means that the effect is not transmitted through prices (i.e., through a market mechanism).
- Examples:
  - consumption of an apple: pecuniary externality, internalized in market prices.
  - pollution/consumption of loud music: these externalities enter directly into the utility or production functions.
- “pecuniary” vs. “non-pecuniary” is not an exogenous, technological definition. Depends fundamentally on markets that are in place.
1. What are externalities?

- Presence of externalities depends on details of the institutional arrangement like definition of commodities and property rights.

- Example: 2 firms: 1 firm pollutes the river and the second firm is a fish farm on that river that suffers from pollution of firm 1. If the two firms merge or if one owns the river and can charge the other for pollution, then external effect gets internalized and there is no longer an externality.

- Old Chicago view (Coase): Can convert all externalities into pecuniary externalities with appropriate markets.

- Note connection to theory of public goods. Public goods are goods that have large-scale productive externalities.
1. What are externalities?

- Key questions:
  1. Theoretical: What is the best way to correct externalities and move closer to the social optimum?
  2. Empirical: How to measure the size of externalities?
2. Correcting Externalities

Consider a two-good model where firms produce cars $x$ using the numeraire $y$.

- Producing $x$ cars entails use of $c(x)$ units of the numeraire and generates pollution ($P$) with marginal damage $d$.
- Consumers have wealth $Z$ and quasilinear utility
  \[ u(x) + y - dP \]
- Social welfare:
  \[ W = u(x) + Z - c(x) - dP \]
- Competitive equilibrium: let $p$ denote price of cars. Firms maximize
  \[ \max px - c(x) \]
- Consumers maximize utility taking pollution as fixed (free rider problem – my car consumption has very little impact on overall level of pollution, so I treat it as fixed and therefore does not affect my optimization):
  \[ \max u(x) + Z - px \]
2. Correcting Externalities

- Demand satisfies
  \[ u'(x^D) = p \]

- Supply satisfies
  \[ c'(x^S) = p \]

- Hence in equilibrium, marginal private benefit equals marginal private cost – the standard optimality condition
  \[ u'(x^D) = c'(x^S) \]
2. Correcting Externalities

Problem: this solution is now not Pareto efficient.

- Marginal damage of production: $MD = d$
- Marginal social cost of production: $c'(x) + d > c'(x)$
2. Correcting Externalities

- Why is there inefficiency? deadweight loss triangle (Gruber figure 1)
2. Correcting Externalities

- Can see this inefficiency formally using a perturbation argument: suppose I reduce production by $dx$. Then

$$dW = u'(x)dx - c'(x)dx - d \cdot dx = -d \cdot dx > 0 \text{ if } dx < 0$$

- Hence social welfare rises if production is reduced and First Welfare Theorem fails.

- Analogous result for consumption externalities. (see figure 2)
  - Social optimum: $Q^*$ such that $MPC = MSB$
  - Market outcome $Q^M$ such that $MPC = MPB$. 

2. Correcting Externalities

- DWL and Consumption externalities (Gruber figure 2)

**Figure 2** Negative Consumption Externalities: Cigarettes
2. Correcting Externalities

Key lessons in a model with externalities:

1. Private markets do not produce Pareto Efficient outcome because firm does not take into account social cost of pollution.

2. Zero pollution is not (necessarily) desirable.

3. Need to know the shapes of MB, MPC, MD to implement $Q^*$. Measurement of MD is especially problematic because you cannot use revealed preference (no market – that is why there is an externality).
2. Correcting Externalities: Remedies for Externalities

1. Establish property rights and create markets for pollution (Coasian solution):
2. Emission taxes or Pigouvian corrective taxation:
3. Regulation: Command and Control
2. Correcting Externalities: Remedies for Externalities

1. Establish property rights and create markets for pollution (Coasian solution):

- Externalities emerge because property rights are not well defined.
- Suppose that the firm pollutes a river. If the river is owned by the consumer, then the firm has no right to pollute the river without the agreement of the consumer.
- In a competitive market, consumer would charge $d$ for every unit of pollution emitted $\rightarrow$ firm’s marginal cost of production becomes $c'(x) + d$. This would restore first-best.
- General point: Creating a market for buying the right to pollute would lead to the Pareto efficient outcome.
2. Correcting Externalities: Remedies for Externalities

Note that it does not matter who is assigned the property rights for the Coasian solution.

- Suppose firm owned the river. Then it would offer to sell the consumer rights access to a less polluted river, and in equilibrium the price for a river that is 1 unit less polluted would be $d$ higher. Thus the firm’s effective opportunity cost of producing a car would be $c'(x) + d$ and efficiency is restored.
- Assignment of property rights affects distribution but not efficiency – all that matters is that we need to create markets.
2. Correcting Externalities: Remedies for Externalities

Two problems with Coasian solution:

1. Cost of bargaining neglected. Cost of bargaining very large when the number of agents involved is large.
   - Example: air pollution, millions of people suffer from atmospheric pollution.
   - Need an association to come in to bargain in the name of agents who are affected. This “association” is precisely the role of the government.

2. Asymmetric information problem: Resource owners need to be able to identify source of damage. For atmospheric pollution, difficult to identify precisely what harm each polluter is doing. Competitive equilibrium can break down if information is not perfect.
2. Correcting Externalities: Remedies for Externalities

2. Emission taxes or Pigouvian corrective taxation:

- Impose a tax equal to the marginal damage inflicted at the optimum $Q^*$. Effective $MPC$ shifts up, and new market equilibrium is at $Q^*$. (see figure 3)

- Optimal Pigouvian tax of $t = d$ restores Pareto efficiency and maximizes welfare in our simple model.

- General principle of optimal taxation in this context: set tax equal to wedge between marginal social cost of production and marginal private cost to restore production efficiency (i.e. set tax equal to marginal damage).
2. Correcting Externalities: Remedies for Externalities

2. Emission taxes (Pigouvian corrective taxation): Optimal pigouvian tax sets \( t = MD(Q^*) \)
2. Correcting Externalities: Remedies for Externalities

Practical problems with corrective taxation

- Need to know MD function to set-up the optimal tax. Hard if MD not constant.
- Think of gasoline tax and car pollution: True that cars produce pollution, but difficult to measure the marginal damage done by cars. What is the optimal Pigouvian tax: European level or US level?
2. Correcting Externalities: Remedies for Externalities

3. Regulation: Command and Control

- Each polluter has to cut pollution down to a certain level or use only certain types of production processes or else face legal sanctions.
- In the simple model sketched above, Pigouvian tax and regulation produce exactly the same outcome.
2. Correcting Externalities: Remedies for Externalities

- **Advantages of regulation:**
  1. Easier to enforce/administer.
  2. Useful to quickly reduce pollution levels if you want to meet a certain salient target. Can be sure to meet a certain target, easier to enforce politically, rather than agree on some taxes that may or may not achieve much of a pollution reduction.

- **Disadvantage of regulation:**
  1. [Dynamics] Discourages innovation: no monetary incentives to discover new technologies to reduce pollution further. With a tax, there is such an incentive.
  2. [Heterogeneity] Inefficient allocation when there is heterogeneity in costs of pollution abatement across firms
2. Correcting Externalities: Remedies for Externalities


- Problems raised above can be addressed using a auction-based permit system.
- Cap total amount of pollution and allow firms to sort out between themselves who pollutes more and less using tradeable permits.
- In equilibrium, firms with highest marginal costs of reducing pollution will end up buying the most permits. Firms that can easily reduce pollution will do so.
- If total number of permits is set to achieve the social optimum, both allocative and productive efficiency will be achieved.
- Also have dynamic incentives to innovate because each firm is bearing a marginal cost of pollution.
- Note that price mechanism (Pigouian tax) also has these desirable properties with heterogeneity and dynamics. So how to choose between price mechanism (tax) and permit (quantity) mechanism? Weitzman (REStud 1974).

- Weitzman’s key insight: When there is uncertainty about MB and/or MC, price and quantity policies may no longer be equivalent.

- Easiest to think about Weitzman’s result in terms of the market for pollution (externality) reduction rather than production of a good.

- Let \( P \) denote amount of pollution reduction starting from private market equilibrium \( (P = 0) \). Let \( B(P) \) denote social benefits of pollution reduction and \( C(P) \) denote social costs.

  - Note: you can map any externality model into a model of costs and benefits of externality reduction. So, the model we considered above implied that the SMB of pollution reduction is constant \( (MD = d) \). [Private MB of abatement is 0.] MC of abatement is the loss in surplus from producing one less car, which is \( u'(x) - c'(x) \). (see figure next slide)

  - More generally, though, there are other ways to reduce costs (technology) besides just reducing production.

- Showing model with MC and MB of abatement (gruber Figure 8) with no uncertainty

Private market equilibrium: PMB=PMC, $P = 0$ (usual result)

Social optimum: SMB=SMC, $P = P^*$

With no uncertainty, can obtain optimum with a quantity policy (do $P^*$) or price policy ($t = MD(P^*)$)
Now suppose that we are uncertain about MB of reducing pollution (marginal damages) – hard to know health costs.

Setup: Regulators use $MB$ (Actual is $MB'$) $\implies$ $tax = T^*$ (when it should be lower). Quantity policy sets $A^*$ when it should be lower.

In this case, P and Q policies both get you to $A^*$ and are inefficient (see DWL). No difference between two policies with this source of uncertainty.

- Now suppose that we are uncertain about MC of reducing pollution – hard to know exactly how much it will cost GM to reduce pollution.
- Setup: Regulators use $MC_1$ (Actual is $MC_2$) $\implies tax = C_2$ (when it should be higher). Quantity policy will set $P_1$ (when it should be $P_2$).
- $P$ policy: tax will get pollution to $P_3$ (when it should be $P_2$) and DWL is small triangle.
- $Q$ policy: will get to $P_1$ (when it should be $P_2$) and DWL is large triangle.

- But if the MB (≡MSB) curve is steep (steeper than MC), then DWL of P policy is larger than Q policy.

Intuition: With flat MD curve, then tax is likely to be "close." With steep MD curve, then Q is likely to be "close."

- Steep MD curve is the case of a very risky outcome—nuclear leakage.
4. Empirical Applications

- Measuring externalities is hard because there is by definition no direct market that can be used to recover willingness-to-pay. If there were a market, there would be no externality.
- Two approaches: indirect market-based methods and contingent valuation
- Chay and Greenstone JPE is example of indirect market method
4. Empirical Applications: Chay and Greenstone JPE

- **Question:** can we value the impact of pollution on housing prices. This is one part of the MD of pollution or alternatively the WTP for clean air.

- Existing literature uses cross section variation in (levels of or changes in) pollution. Inconsistent findings, some with wrong sign.

- **Their approach**
  - Use exogenous variation from Clean Air Act, assigns counties to attainment and nonattainment status based on clear decision rule
  - Estimate as reduced form and IV. Overall and as RD.
  - Results are robust and show larger effects on property prices than prior literature.

- Paper is a great example of classic Ken Chay paper: hands above the table, showing you all of the supporting information so that you believe the results are causal.
4. Empirical Applications: Chay and Greenstone JPE

- **Clean Air Act 1970**
- First significant federal environmental legislation (prior to this, some states had laws, most did not).
- Set air quality standards for 5 pollutants (in this paper they focus on TSPs)
- Law established that EPA would assign "attainment/nonattainment" status to each county annually. Nonattainment defined as meeting either one of 2 conditions:
  1. annual mean concentration > 75
  2. second highest daily concentration exceeds 260 (bad day)
- If nonattainment, then state is responsible for making plan for fix it.
4. Empirical Applications: Chay and Greenstone DATA

1. Pollution monitors
2. TSP attainment/nonattainment (they could not get data from EPA so they calculated this themselves)
3. Housing values (1970, 1980 Census). [Public use census micro data does not identify county of residence. Either use county averages from the summary files or use data in Census Restricted Data Center.]

They argue (and present evidence) that attainment status in 1976 is preferred rather than 1972. They then relate this to 1970-1980 changes in housing value
What is a hedonic model?
Rosen (1974), empirical approach aimed at estimating value of non-market amenities (characteristics of homes, location, schools, weather, etc). Here the application is pollution.

Why is the prior literature subject to a bias?

\[ y_c = \theta T_c + X_c \beta + \epsilon_c \] or in differences \[ \Delta y_c = \theta \Delta T_c + \Delta X_c \beta + \epsilon_c \]

Could be third factor driving both pollution and housing values. What is shifting pollution?

Cross-section bias: Bias toward wrong (+) sign because high pollution areas are urban, etc

Changes bias: Biased toward wrong (+) sign because areas local labor markets may be shifting both (recession means less pollution and lower housing prices)

Selection bias: do people sort into areas based on MWTP?
4. Empirical Applications: Chay and Greenstone JPE

- Their approach is to use the attainment status as an instrument for pollution
- first stage: \( \Delta T_c = \Delta X_c \beta + Z_c \Pi_{TZ} + \nu \) where \( Z \) is the instrument
- reduced form: \( \Delta y_c = Z_c \Pi_{yZ} + \Delta X_c \beta + \epsilon_c \) (this is the program evaluation estimate, interesting in its own right)
- second stage: \( \Delta y_c = \theta \Delta T_c + \Delta X_c \beta + \epsilon_c \)
- Turns out that the IV estimate when the instrument is 0/1 is just the ratio of the \( \theta_{IV} = \Pi_{yZ} / \Pi_{TZ} \) called the wald estimator.
4. Empirical Applications: Chay and Greenstone JPE

- 1976 attainment status: they argue that this is preferrable because (1) pre-trends match up, (2) observables balanced, and (3) less time to respond and move.
4. Empirical Applications: Chay and Greenstone JPE

- Compare those above the threshold to those below (RD) (50-75, 75-100) and control for smooth function in pollution.
- Compare those below the threshold with same average, attainers vs nonattainers (had a "bad day").

![Graph showing attainment in 1975 and nonattainment in 1975.]

Fig. 4.—1970–80 change in mean TSPs by 1975 nonattainment status and the geometric mean of TSPs in 1974.
4. Empirical Applications: Chay and Greenstone JPE

- Col 1: difference in mean Xs between areas with above vs below median pollution, bias towards wrong (+) sign (dirty areas are higher price)
- Col 2: shows procyclical pollution; increase in economic activity leads to higher prices and more pollution (bias towards wrong + sign)
- Cols 3-4 shows balance between T (nonattainers) and C (attainers) group is better in 1976 attainment rule

<table>
<thead>
<tr>
<th>TABLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIFFERENCES IN SAMPLE MEANS BETWEEN GROUPS OF COUNTIES, DEFINED BY TSPs LEVELS, CHANGES, OR NONATTAINMENT STATUS</strong></td>
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<table>
<thead>
<tr>
<th></th>
<th>TSPs Nonattainment</th>
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<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Total counties (nonattainment)</td>
<td>988</td>
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<tr>
<td>Housing value</td>
<td>1,092</td>
</tr>
<tr>
<td>(918)</td>
<td>(713)</td>
</tr>
<tr>
<td>Mean TSPs</td>
<td>39.2**</td>
</tr>
<tr>
<td>(12)</td>
<td>(10)</td>
</tr>
<tr>
<td>Economic condition variables:</td>
<td></td>
</tr>
<tr>
<td>Income per capita (1982-84 dollars)</td>
<td>377.7**</td>
</tr>
<tr>
<td>(94.7)</td>
<td>(107)</td>
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<tr>
<td>Total population (% change)</td>
<td>142,916**</td>
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<tr>
<td>(24,279)</td>
<td>(913)</td>
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<tr>
<td>Unemployment rate (× 100)</td>
<td>-1.14</td>
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<tr>
<td>(120)</td>
<td>(129)</td>
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<tr>
<td>% employment in manufacturing (× 10)</td>
<td>0.98</td>
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<tr>
<td>(083)</td>
<td>(026)</td>
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<tr>
<td>Demographic and socioeconomic variables:</td>
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</tr>
</tbody>
</table>
4. Empirical Applications: Chay and Greenstone JPE

- Estimating OLS models (like the literature). Shows nonrobust and many wrong signed estimates.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>CROSS-SECTIONAL AND FIRST-DIFFERENCE ESTIMATES OF THE EFFECT OF TSPs</th>
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<tbody>
<tr>
<td></td>
<td>Mean TSPs (1/100)</td>
</tr>
<tr>
<td>A. 1970 Cross Section</td>
<td></td>
</tr>
<tr>
<td>Mean TSPs (1/100)</td>
<td>.032</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.00</td>
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<td>Sample size</td>
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<tr>
<td>B. 1980 Cross Section</td>
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<td>Mean TSPs (1/100)</td>
<td>.093</td>
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<tr>
<td>$R^2$</td>
<td>.00</td>
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<td>C. 1970–80 (First Differences)</td>
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<td>Mean TSPs (1/100)</td>
<td>.102</td>
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<td>$R^2$</td>
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<td>Flexible form of county covariates</td>
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<tr>
<td>Region fixed effects</td>
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</tbody>
</table>
4. Empirical Applications: Chay and Greenstone JPE

- 1st stage (good power) and reduced form (shows value of policy). Robust. Ratio of estimates gives IV (Wald).

<table>
<thead>
<tr>
<th>TABLE 4</th>
<th>ESTIMATES OF THE IMPACT OF MID-DECADE TSPs NONATTAINMENT ON 1970–80 CHANGES IN TSPs POLLUTION AND LOG HOUSING VALUES</th>
</tr>
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<tbody>
<tr>
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<td>(1)</td>
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<tr>
<td>A. Mean TSPs Changes</td>
<td></td>
</tr>
<tr>
<td>TSPs nonattainment in 1975 or 1976</td>
<td>-9.96</td>
</tr>
<tr>
<td>( F )-statistic TSPs nonattainment*</td>
<td>(1.78)</td>
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<td>( R^2 )</td>
<td>.04</td>
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<td>B. Log Housing Changes</td>
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<td>TSPs nonattainment in 1975 or 1976</td>
<td>.036</td>
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<td>( F )-statistic TSPs nonattainment*</td>
<td>(8.5)</td>
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<td>Region fixed effects</td>
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</table>
4. Empirical Applications: Chay and Greenstone JPE

- IV estimates.

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<td>A. TSPs Nonattainment in 1975 or 1976</td>
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<tr>
<td>Mean TSPs (1/100)</td>
<td>-.362</td>
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<td>-.266</td>
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<tr>
<td>B. TSPs Nonattainment in 1975</td>
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<td>Mean TSPs (1/100)</td>
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<td>(.084)</td>
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<td>C. TSPs Nonattainment in 1970, 1971, or 1972</td>
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<td>Mean TSPs (1/100)</td>
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<td>no</td>
<td>no</td>
<td>yes</td>
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</table>
4. RD results

- This is an early version of a regression discontinuity paper. You do not see the figures and specifications that are usually presented in an RD setting.
- Table 6: running variable is quadratic in TSPs.
- Loss of precision but estimates similar.
4. Empirical Applications: Indirect Market-Based Methods

- Results: 1% increase in pollution $\rightarrow$ 0.2-0.35% decline in house values.

- Fairly large WTP for cleaner air. Suggest that clean air act increased (on net) house values by 45 billion in nonattainment counties.

- Possible concern: Coefficients in home price regressions decline across specifications with more controls. Often a sign of omitted variables.

- Concern with these short-run market based methods: People may be ignorant of changes in pollution in short run and effects on health, and thus market price difference might not reflect the real societal cost of pollution.

- This is the tip of a large literature on environmental economics. Particularly active in the context of assessing consequences of global warming and optimal response.
4. Other papers estimating MD of pollution

- Large Literature on impacts of pollution on child health
  - Natality & Mortality data, birthweight & infant mortality
  - Uses various research designs to identify causal impacts on birth outcomes and infant mortality
  - Chay and Greenstone (2003), economic shock as instrument for pollution, infant mortality
  - Economic activity, traffic, pollution (Knittel, Miller, Sanders 2010, Currie and Walker 2009)
  - Chernobyl fallout (Almond, Edlund, Palme 2007)
  - Mother fixed effects (Currie, Neidell & Schmieder 2009)


- Also see Currie (2011, AER Ely Lecture) for broader literature on child health, with pollution being one piece of her review.

- Many papers have explored the impacts of pollution on health (hospitalizations, physicians visits, mortality, infant health), to date we know little about the complicated mechanisms at play. We know little about impacts on labor supply.
- This paper makes an important contribution by providing evidence on the impact of pollution on productivity.
- This is hard to analyze: cross sectional correlations yield biases, people may engage in compensating behavior (stay in when air is bad)
- The setting is agricultural and the data is well suited to study the problem:
  - daily panel data on worker output (crops picked) for Central Valley farm
  - Need productivity measures to calculate pay, since paid piece rates
  - Merged with data on environmental conditions from air quality and metrology stations
  - spans periods with varying ambient air pollution
  - labor supply of agricultural workers is relatively inelastic, so they argue that they are capturing the intensive margin and productivity.
4. Graff Zivin & Neidell (AER, 2012), Details

- Data on workers
  - Information coded each time worker brings in bushel (crop, time, location of field, gender)
  - 2009 and 2010 growing season data (600 workers, 155 days)
  - Crops: blueberries, two types of grapes

- Compensation: time plus pieces
  - $TPP : w = 8h + p(q - \min pcs \times h)I(q > \min pcs \times h)$
  - $TPAP : w = 8h + pqI(q > \min pcs \times h)$
  - at hours (h), threshold quantity (minpcs)
  - This compensation scheme creates some challenge in that incentives are not continuous. (They examine this with robustness estimating censored tobit models; results little changed)

- Pollution: hourly ozone from stations between 10-20 miles away (average between 6am-3pm)
4. Graff Zivin & Neidell (AER, 2012), Model and Identification

- Controls include:
  - Fixed effects for day of week, year-month, crop
  - Gender, tenure, precipitation, wind speed, air pressure, fine particulate matter
  - Fine bins for confounders: temperature (2.5 degree bins interacted with solar radiation), humidity
  - Can also include worker fixed effects

- Robustness they show more flexible impacts of ozone (with dummies instead of linear)

- Standard errors two way clustered: worker, date
Variation in temperature and worker output

Figure 4. Average demeaned daily ozone and temperature and crop harvest days, by year

A. Year 2009
4. Graff Zivin & Neidell (AER, 2012), Results

- Main results, Table 3: 10 ppb increase in ozone leads to a .14 SD decrease in productivity
- Table 2: no impact on labor supply
- Table 4: relatively insensitive to worker fixed effects, others
4. Graff Zivin & Neidell (AER, 2012), Results

- Heterogeneity: no impact with tenure, smaller impact for women
- Crop 1 = blueberries (hard, close to the ground), crop 2 = grapes (a delicate variety, slower to harvest), crop 3 = other grape. Results consistent with ordering of productivity effects $1 > 3 > 2$.

Table 5. Heterogeneity of regression results of the effect of ozone on productivity

<table>
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<tr>
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<tr>
<td>ozone (10 ppb)</td>
<td>-0.143**</td>
<td>-0.149**</td>
<td>-0.169**</td>
<td>-0.135*</td>
<td>-0.006</td>
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<td>[0.075]</td>
<td>[0.069]</td>
<td>[0.076]</td>
<td>[0.041]</td>
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<tr>
<td>ozone (10 ppb)*female</td>
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<td>-0.216***</td>
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<tr>
<td>ozone (10 ppb)*crop2</td>
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<td>0.149**</td>
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<td>[0.060]</td>
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</tbody>
</table>
4. Graff Zivin & Neidell (AER, 2012), Results

- **Sensitivity:** remarkably linear impact of ozone (they estimate model with dummies for bins of ozone rather than simple linear ozone, omitting <30ppb)

  Figure 5. Regression results of the effect of ozone on productivity using more flexible controls for ozone