Theory and Measurement

A Perspective on Empirical Economics

Phil Haile

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Types of Empirical Work: A Functional Taxonomy?

1. Measurement
   - how much do prices change with the number of competitors?
   - how has productivity (e.g., TFP) in the U.S. auto industry changed over the last 30 years?
   - what is the effect of college attendance on expected wage?
   - what is the elasticity of aggreg demand for health insurance?
2. Model Testing
   - Is there evidence of moral hazard in auto insurance?
   - Does BNE do well in predicting bidding at oil auctions?
   - Do actual contracts resemble optimal contracts?
3. Model Estimation for Counterfactuals
   - How much would prices rise two firms merged? if the sales tax increased by 1%?
   - How would student outcomes differ under a different school choice mechanism?

Measurement vs. "Model Estimation for Counterfactuals"

This distinction is *usually* false: Most "measurement" questions in economics concern a counterfactual of the form "how would the world have been different if ______ were changed with all else held fixed?"

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- *elasticity of demand*: can't just compare quantities purchased for goods with high prices vs. those with low prices.

Types of Empirical Work: A Better Taxonomy?

1. **Descriptive**: estimate relationships between observables
   - establish facts: e.g.,
     - college grads earn 98% more per hour than others
     - income inequality higher now than 30 years ago
     - health care costs growing more slowly after ACA
     - airline prices higher now than before merger wave
   - facts sometimes suggest causal relationships
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   - estimate demand for schools→predict outcomes under a voucher system
   - estimate model of schooling, marriage, and labor supply choices→measure true male-female wage gap
   - estimate demand and firm costs→predict the welfare effects of a merger.

What about Program Evaluation?

Consider a RCT with interest only in the effect of the treatment in the population studied.

Here, program evaluation is *descriptive:* it involves only a characterization of relationships between observables.

It is also *structural*: it quantifies features of the underlying ("causal"/"structural") model characterized by the joint distribution

$$F(Y, D, X)$$

where $D \in \{0, 1\}$ indicates treatment, Y measures outcome, X are "controls."

What about Program Evaluation?

Program evaluation is ALWAYS structural estimation.

Sometimes data description reveals a structural quantity like TT. But that is a *result*—one that follows from an explicit set of assumptions on the underlying structure. TT, ATE, LATE, QTE, etc. are all precisely defined only under a well specified model of how the data are being generated

Typically program evaluation requires more than descriptive analysis: one must *counterfactually* hold *all else equal* in order learn the effect (a.k.a. "causal effect") of D on Y, given X. This means treating $F(Y, D, X)$ (or a functional of F like LATE) as the structural feature of interest and using appropriate econometric techniques (IV, diff-in-diff, RD,...) to estimate it.

“Causal” Efffects/Inference?

Causality is always defined by a counterfactual. (e.g., Pearl)

“Causal inference” is a term sometimes used to signal that one is estimating one of a small set of structural features defined by one of a small set of models. But causal inference is always just a special case of structural estimation/inference as defined in econometrics 60+ years ago.

What about “Reduced Form”?

Definition. A **reduced form** is a functional or stochastic mapping for which the inputs are (i) *exogenous* variables and (ii) unobservables (“structural errors”), and for which the outputs are *endogenous* variables. e.g., $Y = f(X, Z, U)$.

This is the only formal definition I am aware of. In econometrics this goes back at least to 1950. In math, much farther. Economic theorists also use this term.

Where does it come from?

Formally, one obtains a reduced form by *solving a (structural) model* for each endogenous variable as a function of the exogenous observables and structural errors.

The classic example is perfectly competitive supply and demand:

$$\begin{aligned} Q &= D\left(P, X, U_d\right) \qquad \text{(demand)} \\ P &= MC\left(Q, Z, U_s\right) \qquad \text{(supply)} \end{aligned}$$

Solving for equilibrium yields the reduced form relations

$$\begin{aligned} P &= p\left(Z, X, U_s, U_d\right) \\ Q &= q\left(Z, X, U_s, U_d\right) \end{aligned}$$

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Note: Up to functional form restrictions, there is no need to actually *solve*. We just need to know what goes on which side. One could simply *hypothesize* a reduced form. So it is certainly possible to specify a reduced form without explicitly deriving it.

Reduced Form: A Source of Nuance and Confusion

Definition. A **reduced form** is a functional or stochastic mapping for which the inputs are (i) *exogenous* variables and (ii) unobservables ("structural errors"), and for which the outputs are *endogenous* variables.

But what does *exogenous* mean?

- for a theorist, an exogenous variable is one taken as given in (not determined within) the model
- for an econometrician: an exogenous variable is one satisfying some kind of independence condition with respect to unobservables.

These can be different: the fact that something is "given" does not mean it satisfies any independence conditions!

An Example: Firm Pricing

Consider a monopolist with marginal cost function $c(q, t, \epsilon)$ where q is quantity, t is quality, and ϵ is a cost shock (unobserved shifter of costs). Demand is given by $D(p, t, \eta)$ where p is price and η is a demand (e.g., taste) shock. Taking (t, ϵ, η) as given, one can solve for the equilibrium price and quantity:

$$
\begin{aligned}
& p^*(t, \epsilon, \eta) \\
& q^*(t, \epsilon, \eta) = D(p^*(t, \epsilon, \eta), t, \eta).
\end{aligned}
$$

The theorist's reduced forms are $p^*(t, \epsilon, \eta)$ and $q^*(t, \epsilon, \eta)$. From the econometrician's perspective, these may not be reduced forms because t may be correlated with (ϵ, η). For example, such correlation is generally *implied* if t is chosen by the firm with knowledge of (ϵ, η). In that case, t cannot appear on the RHS of a reduced form econometric model.

Example continued

So there is a nuance. But the real issue in the example is that the theorist's model left out something: how t was determined.

That may be fine for the purpose of the theory, but may mean that the econometrician has to *develop a richer model* in which more of the variables are endogenous. This is *always*, at least implicitly, what one is doing when discussing problems of "confounding factors"/selection/endogeneity/IV, etc.

Reduced Form: Some Observations

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3. RF can be used for some types of counterfactuals! (those that do not change the mapping from exogenous variables and structural errors to endogenous outcomes)
4. Sometimes there is no difference between the structural equation and reduced form: e.g., exogenous treatment with $Y = f(X, U)$ and scalar $U \perp X$.

“Reduced Form”

Abuse of Terminology 101

“Reduced form” is sometimes used to mean “equation that I don’t derive, justify, or take questions on, but which I will nonetheless treat as structural (i.e., ‘causal’) when I talk about conclusions”

Often this is combined with use of IV/RD/etc. “identification strategies,” due to endogeneity/selection: e.g., “reduced-form demand model” or “reduced-form estimation of the LATE”

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For this to make any sense, one must mean that the equation is “structural” in the econometrics sense but “reduced form” in the sense of collapsing a more complex model into a simpler representation of inputs and outputs—i.e., a “reduced-form structural model.” A more transparent term for this kind of approach would be “simple structural model.”

"Reduced Form"

Abuse of Terminology 102

Sometimes reduced-form terminology used with the correct intent but without enough care to avoid error. Suppose someone has in mind the supply and demand model

$$\begin{aligned} Q &= D(P, X, U_d) \qquad \text{(demand)} \\ P &= MC(Q, Z, U_s) \qquad \text{(supply)} \end{aligned}$$

but then posits a reduced-form pricing equation of the form:

$$P = g(Z, X, \epsilon) \qquad \epsilon \in \mathbb{R}$$

This pricing equation is consistent with the supply and demand model *only* if the two original structural errors U_d and U_s enter the equilibrium solution through an index $\epsilon(U_d, U_s)$: this is a strong functional form requirement, even when g is unrestricted.

How many structural errors? What are their properties?

This supply and demand example illustrates another general point: it is important to ask what the unobservable(s) are in the relevant economic model, rather than treating them as unnamed "residuals" or "error terms." It is hard to speak coherently about the properties unnamed unobservables!

General Advice: Write down your model and assumptions, naming every term, including all "error terms." Then confirm that your estimation approach yields a consistent estimate of the quantities of interest.

Reduced Form vs. Descriptive

Baby and Bathwater

"Reduced-form" sometimes used to mean descriptive, sometimes to mean "simple structural model," sometimes to mean "sloppy," and sometimes in a way consistent with its formal definition.

Many interesting papers involve descriptive analysis that evaluates model predictions or suggests interesting/important patterns/phenomena that one might investigate further using other methods. And for many questions, the "simple structural model" approach does answer questions of interest. Mis-labeling these things as "reduced-form" causes confusion and guilt by association with sloppy work.

"Structural"

Abuse of Terminology 103

Sometimes "structural" mis-used...

- to describe *how* one estimates rather than *what* one estimates "We *structurally estimate* a model of..."
  - this is confusion
- to mean use of a complex model, or a model with many parametric/functional form assumptions
  - this is completely orthogonal to the question of structural vs. descriptive vs reduced form; more baby with bathwater here
- that one is estimating the "deepest" primitives one thinks of
  - this defines terminology based on the speaker's knowledge/imagination. It is also just incorrect.

“Structural”

Some Observations (Clear already in the 40s and 50s)

Structural estimation can involve estimation of “deep primitives” like distributions of consumer preferences over product characteristics, or “less deep primitives” like aggregate demand elasticities. What matters here is whether the *structural feature* (a functional of the model primitives) estimated is properly defined and sufficient to answer the question you are interested in.

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For example, we don’t need to know entire demand curve to measure change in consumer surplus due to a small price change: local properties of the demand curve are enough.

(See “sufficient statistics” approach: this is actually a *completely standard* type of structural econometrics, used for decades.)

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"Structural"

Some Observations (Clear already in the 40s and 50s)

Likewise, while we can think of "structure" as a set of policy-invariant primitives, what this means will often vary with the kinds of policy or questions we consider. An example is short-run vs. long-run demand elasticities.

Structural estimation can involve estimation/inference on points or sets (e.g., bounds on LATE or on a demand curve).

Structure and Identification

Following, e.g., Hurwicz (1950), Koopmans–Reiersol (1950), Berry-Haile 2018

- a *structure* S is a data generating process, i.e., a set of probabilistic or functional relationships between the observable and latent variables that implies (generates) a joint distribution of the observables
- let $\mathfrak{S}$ denote the set of all structures, $S_0 \in \mathfrak{S}$ the true structure
- a *hypothesis* is any nonempty subset of $\mathfrak{S}$
- hypothesis $\mathcal{H}$ is true (satisfied) if $S_0 \in \mathcal{H}$.
- a *structural feature* $\theta\left(S_0\right)$ is a functional of the true structure.

Structure and Identification (2)

Definition. A structural feature $\theta\left(S_0\right)$ is *identified* (or *point identified*, or *identifiable*) under the hypothesis $\mathcal{H}$ if $\theta\left(S_0\right)$ is uniquely determined within the set $\{\theta\left(S\right) : S \in \mathcal{H}\}$ by the joint distribution of observables. (Equivalently, given $\mathcal{H}$, there are no observationally equivalent structures).

This can be generalized to define "identified sets" as the set of (obsverationally equivalent) structural features consistent with a given distribution of observaionally

Remarks on Identification

- *Identification is not even defined without the notion of a true structure within a class defined by maintained hypotheses (i.e., a model).* The model may be simple or complicated, may involve economics or only hypothesized statistical relationships (e.g., Rubin causal model). But any discussion of identification presumes that there are structural features (abstract notions not part of the data themselves) that one wishes to uncover.
- *Identification has nothing to do with a given sample or an estimator.* In fact, strictly speaking it is not even about what one could learn from an infinitely large sample.
- *Identification is necessary but not sufficient* for existence of suitable estimators.

Does all this language really matter?

Or is this only Phil's pet peeve?

"Oxford English Dictionary View": A word's everyday use determines its meaning, not the other way around. It is nonsense to assert that a word's common use is incorrect.

Does this language really matter?

Or is this only Phil's pet peeve?

My View:

(1) Misuse (even inconsistent use) of terminology destroys information. This may be mildly annoying or amusing in everyday conversation

> *"I literally died laughing when I heard what Josh Angrist said about empirical IO!"*

but is sloppiness that should be avoided in serious scholarship.

(2) The language we use shapes the way we think—for example about how we approach data, trade-offs between alternative methods, etc. Precise language encourages precise thinking.

(3) We should be especially wary of intentional or accidental *exploitation of imprecise language*, e.g., using "reduced form" or "structural" as excuses.

The Role of Economic Models in Empirical Work

We are economists, not statisticians.

- Statisticians are good at describing the data.
- Economists are good at interpreting it using formal logic:

  given a set of maintained hypotheses, the data imply . . . .

- Where to the maintained hypotheses come from? How can they be evaluated? How do we know which maintained hypotheses are useful?

The Role of Economic Models in Empirical Work

Most good empirical work in economics will exploit economic models to provide a logical framework (set of maintained or testable hypotheses) for interpreting the raw data:

- to tell us what to look at: what are the structural features of interest for our questions? One should not define the object of interest based only on what some statistical procedure produces.
- to define what it means to have a "valid" estimation method
- to provide equilibrium relationships that can be used to estimate of the structural features of interest; e.g.,
  - optimality conditions that relate observables to primitives
  - IV conditions (absent an experiment, what are valid instruments? this requires economic reasoning, which means at least an informal model)
  - what observables and structural errors must be in the reduced form.

The Role of Economic Models, An Example: Part 1

- A researcher observes price P and quantity Q of a good in many markets
- He says: "I do not want to impose arbitrary restrictions from a model on the data. I want to let the data speak for themselves, revealing the true causal relationships"
- He regresses Q on P and finds a positive correlation and concludes "Initial evidence suggests that P has a positive effect on Q."
- He then adds some covariates X to the regression and obtains similar results. The researcher concludes, "the positive effect of P on Q is robust to the inclusion of a rich set of controls."

(So far, nonsense.)

An Example: Part 2

- The researcher now considers the use of instrumental variables methods, characterizing this either as a robustness check on the original "reduced form" analysis, or as a way for controlling for possible "confounds"
- The researcher points out that $Z^{(1)}$, a measure of the availability of a substitute goods, was not part of X and suggests using this variable as an instrument for P. TSLS now reveals a stronger positive "causal effect" of P on Q. The researcher concludes that the original results are qualitatively robust, but that controlling for endogeneity of P eliminates a downward bias in the OLS estimates.

(still nonsense)

An Example: Part 3

- Another researcher reads the paper and has a different idea for an instrument: the manufacturing wage in the local market, something also left out of X that plausibly affects prices.
- TSLS now yields a precisely estimated *negative* "causal effect" of price on quantity
- The researcher concludes, "the causal effect of P on Q is heterogeneous. The effect one measures depends on which prices are changing in response to variation in the instrument one uses."

(more nonsense).

Why Do We Know This Is Nonsense?

Our researcher started with a common approach: he (correctly!) conjectures that X may affect Y, and explores the relationship with regression, with or without IV, interpreting at least the latter as "the causal effect of X on Y." Where did he go wrong? How do *we know* that something has gone wrong?

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Here it is clear to us that something is wrong because we already have a deeply ingrained idea of how prices and quantities are determined in a market, and of what variables are likely to be "demand shifters" or "cost shifters;" i.e., *we have a structural model in mind.*

Avoiding Nonsense

Once the researcher suspects that there may be omitted factors, selection, endogeneity, etc., *a model is necessary* to determine what "fixes" will work (indeed, what "work" even means) .

- in the example a model is needed even to recognize demand and supply as distinct objects—that *there is no such thing as "the causal effect of* P *on* Q*"*
- typically we need a model to even define what quantities should be measured
- typically we need a model to reveal what is a valid IV (what "valid" even means), how many are needed, etc., e.g.
  - excluded cost shifters (manuf wages) to identify demand
  - excluded demand shifters (availability of substitutes) to identify supply
  - both belong in the true reduced forms (one for P, one for Q).

The Role of Models

Stepping Back

"all models are wrong, but some are useful." – George Box

Useful because without a model there is often only hand waving. Attempts to go beyond data description without a model are "not even wrong" — i.e., one cannot even define what "right" means.

The Role of Models

Stepping Back

"Art is not truth. Art is a lie that makes us realize truth..." – Pablo Picasso

The art of empirical work includes selecting a model that captures essential features *for the purpose at hand* and allows one to justify an interpretation of a measurement. One can then speak clearly about whether the maintained assumptions are problematic, whether data allow precise measurement, what alternative assumptions might imply, etc.

Fun Reading

Koopmans, T. (1947). "Measurement Without Theory," Cowles Foundation Discussion paper 25a. http://www.jstor.org/stable/1928627

Koopmans, T. (ed) (1950). *Cowles Monograph 10. Statistical Inference in Dynamic Economic Models*, London: Wiley. (esp. chapters by Hurwicz, Koopmans) http://cowles.yale.edu/sites/default/files/files/pub/mon/m10-all.pdf

Marschak, J. and W.C. Andrews Jr. (1944), "Random Simultaneous Equations and the Theory of Production," *Econometrica*, 12, 143-205., http://www.jstor.org/stable/1905432