An Empirical Equilibrium Model of a Decentralized Asset Market

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Motivation:

- Many long-lived goods/assets have very active markets:
  - Consumer durables (cars);
  - Real assets/Capital equipment (real estate, aircraft);
  - Financial assets (T-bills; corporate bonds; derivatives).
- Almost all these asset markets are decentralized.
  Key features:
  1. search for trading partners (frictions);
  2. bargaining over prices;
  3. intermediaries (e.g., dealers).
- Large theoretical literature on search/decentralized markets;
- Smaller empirical literature. Mainly labor markets, some financial markets.

This paper (1)

- EMPIRICAL QUESTIONS:
  - How large are search frictions?
  - How they affect asset allocation and asset prices?
  - How do intermediaries affect allocation and prices?

- BUSINESS AIRCRAFT:
  - ideal ground for testing:
    - Decentralized market;
    - Secondary markets active;
    - Good data (?).

This paper (2):

- Setup a search-and-bargaining model of a decentralized asset market (extend Duffie, Gârleanu and Pedersen, 2005);
- Estimate it using Business Aircraft;
- Two counterfactuals:
  1. Walrasian market.
     Quantify the effects of frictions on asset allocations and prices.
  2. No dealers.
     Quantify the effects of dealers on asset allocations and prices.
- To my knowledge, first paper to estimate a bilateral search model that investigates microstructure and equilibrium of the market of a capital asset/durable good.

Literature

- Search-Decentralized Markets:
  Too many to list since Diamond (1984). More closely related bilateral search (Rubinstein and Wolinsky, 1985, 1987; Mortensen and Wright, 1998) and recent papers on search in financial markets (Duffie, Gârleanu and Pedersen, 2005; Weill, 2007; Vayanos and Weill, 2008).

- Secondary Markets/Durable goods:
  Rust (1985); Anderson-Ginsburgh (1994); Hendel-Lizzeri (1999); Waldman (1997); Gilligan (2006); Gavazza (2011a, 2011b).

- Intermediaries:
  O'Hara (1995) on dealers in financial markets; Spulber (1999).
  Empirics: Hall and Rust (2000), Gavazza (2011a).

- Structural estimation of search models:
  Labor markets: Survey of Eckstein and van der Berg (2006).

Data (1)

1. *Aircraft Transactions:*
   For each month from January 1990 to December 2008 and for each model (e.g., Cessna Citation V or VI):
   - active fleet (e.g., the number of active aircraft; new deliveries);
   - number of aircraft for sale, by owners and by dealers;
   - completed transactions (e.g., the total transactions; retail transactions; dealer transactions);
   - aircraft characteristics.
2. *Aircraft Bluebook Price Digest:*
   Unbalanced panel of historic prices of different vintages for the most popular business aircraft during 1990–2008. Two series:
   - Retail prices: average transaction prices between final users.
   - Wholesale prices: average transaction prices between an owner (seller) and a dealer (buyer).

   All values are in U.S. dollars, and I have deflated them using the GDP Implicit Price Deflator, with 2005 as the base year.

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Data: Summary statistics

Panel A: Aircraft Transactions	Obs.	Mean	St. Dev.	Median
Models of Aircraft	26,237	161		
Active Aircraft	26,237	89.79	107.28	49
Aircraft for Sale	26,237	10.91	15.11	6
–by Owners	26,237	7.75	11.94	4
–by Dealers	26,237	3.16	4.78	2
Average Age, Aircraft for Sale	23,225	18.43	11.09	19
Retail-to-Retail Transactions	26,237	0.58	1.12	0
Retail-to-Dealer Transactions	26,237	0.83	1.48	0
Dealer-to-Dealer Transactions	26,237	0.28	0.78	0
Dealer-to-Retail Transactions	26,237	0.83	1.50	0
Total Number of Transactions	26,237	1.42	2.29	0
Panel B: Aircraft Prices				
Models of Aircraft	31,524	72		
Retail Price (in $1,000)	31,524	7,607	8,534	4,343
Wholesale Price (in $1,000)	31,524	6,731	7,555	3,849
Age (in Years)	31,524	14.43	9.69	13.25

Data (3)

- Advantages:
  - Rich description of business aircraft market.
  - Good info on how many aircraft are for sale at any point in time (i.e., trading frictions).
  - Retail and Dealer Transactions.
  - Blue Book price data: estimates of agents' aircraft valuation and aircraft depreciation.
- Disadvantages:
  - Impossible to identify sales intermediated by brokers.
  - Aggregate dealer inventories.
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Model: Assumptions (1)

- Continuous time. Infinite Horizon. Discount $\rho > 0$.

- Mass μ of entrants at every instant. Entrants' valuation of the asset z_h. Valuation switches to absorbing state $z_l < z_h$ at rate λ. Each agent can own either 0 or 1 asset.

- Flow x of new durable assets, allocated to new entrants.
  "Life" T periods.
  $xT < \frac{\mu}{\lambda}$ mass of high-valuation agents.
  An aircraft of age a generates the instantaneous flow of utility $z\left(\delta_1 e^{-\delta_2 a}\right)$ to his owner with valuation $z \in \{z_l, z_h\}$.

- (Endogenous) Mass μ_d of dealers. Flow fixed cost k. At most one unit of inventory. Free entry.

Model: Assumptions (2)

- Agents wishing to trade pay a flow search cost c_s.
- Random matching: Agent wishing to trade makes contacts with other agents pairwise independently at Poisson arrival times with intensity γ, and dealers at rate γ'.
  1. A seller's arrival rates are $\gamma_s = \gamma\mu_b$ (buyers) and $\gamma_{sd} = \gamma'\mu_{db}$ (dealers with no aircraft).
  2. A buyer's arrival rates are $\gamma_b(a) = \gamma\mu_s(a)$ (sellers of age-a) and $\gamma_{bd}(a) = \gamma'\mu_{ds}(a)$ (dealers with age-a aircraft).
- Buyers, sellers and dealers bargain over price. Generalized Nash bargaining. θ_s is sellers' bargaining power (when selling to buyers), and θ_d dealers'.

Value functions

- Four type of agents (+ two type of dealers): high- and low-valuation owners and non-owners $\{ho, lo, hn, ln\}$.

- Gains from trade: low-valuation owners meet high-valuation non-owners. Gains from trade larger when aircraft is young: Not all meetings result in trade.

- Value functions (young assets, always traded):

$$
\begin{aligned}
\rho U_{ho}(a) &= z_h\left(\delta_1 e^{-\delta_2 a}\right) + \lambda\left(S_{lo}(a) - U_{ho}(a)\right) + U'_{ho}(a), \\
\rho S_{lo}(a) &= z_l\left(\delta_1 e^{-\delta_2 a}\right) - c_s + \gamma_s\left(p(a) + U_{ln} - S_{lo}(a)\right) + \\
&\quad \gamma_{sd}\left(p_B(a) + U_{ln} - S_{lo}(a)\right) + S'_{lo}(a), \\
\rho S_{hn} &= -c_s + \lambda\left(U_{ln} - S_{hn}\right) + \int \gamma_b(a) \max\left\{U_{ho}(a) - p(a) - S_{hn}, 0\right\} da \\
&\quad \int \gamma_{bd}(a) \max\left\{U_{ho}(a) - p_A(a) - S_{hn}, 0\right\} da, \\
\rho U_{ln} &= 0.
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$S_i(\cdot)$ trading agent; $U_i(\cdot)$ non-trading agent.

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$S_i(\cdot)$ trading agent; $U_i(\cdot)$ non-trading agent.

Dealers

- Two type of dealers, with and without inventory.

- A dealer sells at rate $\alpha_{ds} = \gamma' \mu_{hn}$ and buys a vintage-a aircraft at rate $\alpha_{db}(a) = \gamma' \mu_{lo}(a)$. Margin (i.e., bid-ask spread) $p_A(a) - p_B(a)$.

- Value functions:

$$\begin{aligned} \rho J_{do}(a) &= \max\left\{-k + \alpha_{ds}\left(p_A(a) + J_{dn} - J_{do}(a)\right) + J'_{do}(a), \rho J_{dn}\right\}, \\ \rho J_{dn} &= -k + \int \alpha_{db}(a) \max\left\{J_{do}(a) - p_B(a) - J_{dn}, 0\right\} da \end{aligned}$$

  k fixed flow cost.

- Free entry implies $J_{dn} = 0$.

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Policy Functions

Agents' cutoffs:

- a^*_{ho} : *ho*-agents scrap their assets when it reaches age a^*_{ho};
- a^*_{hn} : *hn*-agents purchase an asset if younger than $a^*_{hn} \leq a^*_{ho}$;
- a^*_l : *lo*-agents sell their aircraft if it is younger than a^*_l, but keep it if it is older. Equilibrium requires $a^*_l \leq a^*_{hn}$.

Dealers' cutoffs:

- a^*_{dn}: dealers do not purchase aircraft older than a^*_{dn};
- a^*_{do}: dealers scrap aircraft when they reach age $a^*_{do} \geq a^*_{dn}$.

Evolution of agents (1)

- Masses of owners evolve according to:

$$
\begin{aligned}
\dot{\mu}_{ho}(a) &= \left(\gamma_b(a)\,\mu_{hn} + \gamma_{bd}(a)\,\mu_{hn}\right) - \lambda\mu_{ho}(a) \text{ for } a < a^*_{ho}, \\
\dot{\mu}_{lo}(a) &= \lambda 1\left(a < a^*_{ho}\right)\mu_{ho}(a) - \gamma_s 1\left(a < a^*_l\right)\mu_{lo}(a) + \\
&\quad -\gamma_{sd} 1\left(a < \min\{a^*_l, a^*_{dn}\}\right)\mu_{lo}(a) \text{ for } a < T, \\
\dot{\mu}_{do}(a) &= \alpha_{db}(a)\, 1\left(a < a^*_{dn}\right)\mu_{dn} - \alpha_{ds}\mu_{do}(a) \text{ for } a < a^*_{do}.
\end{aligned}
$$

- Initial conditions: $\mu_{ho}(0) = x$ and $\mu_{lo}(0) = \mu_{do}(0) = 0$.
- Terminal conditions: $\mu_{ho}(a) = 0$ for $a^*_{ho} \leq a < T$ and $\mu_{do}(a) = 0$ for $a^*_{do} \leq a < T$.

Evolution of agents (2)

- Mass of non-owners:

$$\dot{\mu}_{hn} = (\mu - x) + \mu_{ho}(a^*_{ho}) - \lambda\mu_{hn} - \mu_{hn}\int_0^{a^*_l}\gamma_b(a)\,da - \mu_{hn}\int_0^{a^*_{dn}}\gamma_{bd}(a)\,da,$$

$$\dot{\mu}_{dn} = \alpha_{ds}\int_0^{a^*_{do}}\mu_{do}(a)\,da - \mu_{dn}\int_0^{\min\{a^*_l,a^*_{dn}\}}\alpha_{db}(a)\,da + \mu_{do}(a^{**}_{dn}),$$

$$\mu_{ln} = \lambda\mu_{hn} + \gamma_s\int_0^{a^*_l}\mu_{lo}(a)\,da + \gamma_{sd}\int_0^{\min\{a^*_l,a^*_{dn}\}}\mu_{lo}(a)\,da + \mu_{lo}(T).$$

- In steady-state, $\dot{\mu}_{hn} = \dot{\mu}_{dn} = 0$.
- In steady-state, high-valuation agents $\mu_{hn} + \int\mu_{ho}(a)\,da = \frac{\mu}{\lambda}$.
- Mass of dealers: $\mu_d = \int\mu_{do}(a)\,da + \mu_{dn}$.
- Market clearing: $A = \int(\mu_{ho}(a) + \mu_{lo}(a) + \mu_{do}(a))\,da$.

Evolution of agents (2)

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\dot{\mu}_{hn} &= (\mu - x) + \mu_{ho}(a_{ho}^{*}) - \lambda\mu_{hn} - \mu_{hn}\int_{0}^{a_l^{*}}\gamma_b(a)\,da - \mu_{hn}\int_{0}^{a_{dn}^{*}}\gamma_{bd}(a)\,da, \\
\dot{\mu}_{dn} &= \alpha_{ds}\int_{0}^{a_{do}^{*}}\mu_{do}(a)\,da - \mu_{dn}\int_{0}^{\min\left\{a_l^{*},a_{dn}^{*}\right\}}\alpha_{db}(a)\,da + \mu_{do}(a_{dn}^{**}), \\
\mu_{ln} &= \lambda\mu_{hn} + \gamma_s\int_{0}^{a_l^{*}}\mu_{lo}(a)\,da + \gamma_{sd}\int_{0}^{\min\left\{a_l^{*},a_{dn}^{*}\right\}}\mu_{lo}(a)\,da + \mu_{lo}(T).
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- Market clearing: $A = \int \left(\mu_{ho}(a) + \mu_{lo}(a) + \mu_{do}(a)\right)da$.

Prices:

When a buyer and a seller meet, the negotiated price

$$p(a) = (1-\theta_s)(S_{lo}(a) - U_{ln}) + \theta_s (U_{ho}(a) - S_{hn})$$

solves the symmetric-information bargaining problem:

$$\max_{p(a)} [U_{ho}(a) - p(a) - S_{hn}]^{1-\theta_s} [p(a) + U_{ln} - S_{lo}(a)]^{\theta_s}$$

s. to: $\quad U_{ho}(a) - p(a) - S_{hn} \geq 0$ and $p(a) + U_{ln} - S_{lo}(a) \geq 0.$

Similarly, the ask and bid prices $p_A(a)$ and $p_B(a)$ satisfy:

$$\begin{aligned} p_A(a) &= (1-\theta_d)(J_{do}(a) - J_{dn}) + \theta_d (U_{ho}(a) - S_{hn}), \\ p_B(a) &= (1-\theta_d)(J_{do}(a) - J_{dn}) + \theta_d (S_{lo}(a) - U_{ln}). \end{aligned}$$

Quantitative Analysis: Fixed Parameters

- $\rho = .015$ (quarterly);
- $\delta_1 = 1$ (normalization);
- $T = 160$;
- Mass of assets A: average number of per-period aircraft;
- Mass of dealers μ_d: average dealers' capacity.

Moments: Transactions

- Aircraft for sale:

$$\frac{\int_0^{a_l^*} \mu_{lo}(a)\, da + \int_0^{a_{do}^*} \mu_{do}(a)\, da}{A}.$$

- Aggregate dealers' inventories:

$$\frac{\int_0^{a_{do}^*} \mu_{do}(a)\, da}{A}.$$

- Retail-to-retail transactions:

$$\frac{\gamma_s \int_0^{a_l^*} \mu_{lo}(a)\, da}{A}.$$

- Dealer-to-retail transactions:

$$\frac{\alpha_{ds} \int_0^{a_{do}^*} \mu_{do}(a)\, da}{A}.$$

- Average age of aircraft for sale:

$$\frac{\int_0^{a_l^*} a\mu_{lo}(a)\, da + \int_0^{a_{do}^*} a\mu_{do}(a)\, da}{\int_0^{a_l^*} \mu_{lo}(a)\, da + \int_0^{a_{do}^*} \mu_{do}(a)\, da}.$$

Moments: Prices

- Indirect inference procedure. Estimate via non-linear least squares the coefficients of auxiliary equations:

$$\begin{aligned} p(a) &= \beta_0 + \beta_1 e^{-\beta_2 a}, \\ p_B(a) &= \beta_3 + \beta_4 e^{-\beta_5 a}. \end{aligned}$$

- Match coefficients of regressions on simulated data from model.
- Recover z_h, z_l, c_s, δ_2, θ_s, θ_d,
- Recover k from free entry of dealers $J_{dn} = 0$.
- Novel identification of bargaining parameters:
  - Sellers are more likely to sell older aircraft if they enjoy greater bargaining power. Thus, the average age of assets on the market is informative about θ_s and θ_d.
  - Buyers' value function S_{hn} does not vary with the age of the asset and increases with buyers' bargaining powers $1 - \theta_s$ and $1 - \theta_d$. This constant value S_{hn} enters into the intercepts β_0 and β_3, thereby identifying the bargaining parameters.

Parameter Estimates:

λ	0.0457 (0.0035)	z_h	$695,610$ $(41,258)$
γ_s	0.1825 (0.0015)	z_l	$114,060$ $(16,250)$
γ_{sd}	0.1737 (0.0447)	c_s	$1,622.7$ (486.23)
α_{ds}	0.7021 (0.0054)	θ_s	0.3925 (0.0923)
δ_2	0.0167 $(0.1346 * 10^{-3})$	θ_d	0.9732 (0.0054)
γ	$5.9717 * 10^{-5}$ $[3.823; 6.225] * 10^{-5}$	μ	482.3 $[475.7; 733.0]$
γ'	$2.2973 * 10^{-4}$ $[1.444; 2.333] * 10^{-4}$	k	$244,767$ $[232,810; 303,120]$

Notes—This table reports the estimates of the parameters. Asymptotic standard errors, in parentheses. 95-percent confidence intervals in brackets are obtained by bootstrapping the data using 100 replications.

Counterfactual 1: Walrasian Market

- Walrasian market: $\mu^w_{lo}(a) = \mu^w_{do}(a) = 0 \ \forall a$.
- Model with frictions: $\int_0^T (\mu_{lo}(a) + \mu_{do}(a))\, da$.
  Allocative costs of trading frictions (parameters γ_s, γ_{sd} and α_{ds}) depend on how frequently agents seek to trade (parameter λ).
- Walrasian prices are $p^w(a) = \int_a^T e^{-\rho(t-a)} z_h \left(\delta_1 e^{-\delta_2 t}\right) dt$.

Counterfactual 1: Walrasian Market

	(1) Estimated Model	(2) Walrasian Market	(3) $c_s = 0$
$\int_0^T (\mu_{lo}(a) + \mu_{do}(a))\, da$	$1,681$ $[1,646; 2,399]$	0 $[0; 0]$	$1,698$ $[1,683; 2,480]$
$\frac{\int_0^T (\mu_{lo}(a)+\mu_{do}(a))da}{A}$	0.183 $[0.179; 0.256]$	0 $[0; 0]$	0.183 $[0.182; 0.264]$
$\int_0^{a_l^*} \mu_{lo}(a)\, da + \int_0^{a_{do}^*} \mu_{do}(a)\, da$	$1,215$ $[1,202; 1,755]$	0 $[0; 0]$	$1,218$ $[1,152; 1,742]$
$\frac{\int_0^{a_l^*} \mu_{lo}(a)da+\int_0^{a_{do}^*} \mu_{do}(a)da}{A}$	0.132 $[0.130; 0.187]$	0 $[0; 0]$	0.132 $[0.125; 0.184]$
$p(0)$	$17,611,151$ $[17,253; 17,969] * 10^3$	$21,812,709$ $[21,532; 22,145] * 10^3$	$17,648,470$ $[17,249; 18,097] * 10^3$
$p(10)$	$8,437,910$ $[8,366; 8,531] * 10^3$	$11,008,194$ $[10,633; 11,221] * 10^3$	$8,475,461$ $[8,148; 8,672] * 10^3$
Allocations	$2.054 * 10^9$ $[1.942; 2.060] * 10^9$	$2.371 * 10^9$ $[2.324; 2.397] * 10^3$	$2.057 * 10^9$ $[1.941; 2.062] * 10^3$
Search Costs	$6.534 * 10^6$ $[4.817; 14.182] * 10^6$	0 $[0; 0]$	0 $[0; 0]$
Dealers Costs	$244 * 10^6$ $[232.8; 303.1] * 10^6$	0 $[0; 0]$	$255 * 10^6$ $[206.5; 311.6] * 10^6$
Welfare	$1.802 * 10^9$ $[1.614; 1.803] * 10^9$	$2.371 * 10^9$ $[2.324; 2.397] * 10^3$	$1.801 * 10^9$ $[1.632; 1.828] * 10^3$

Note: Worse allocation but higher prices when $c_s = 0$.

Counterfactual 2: No dealers ($\gamma' = 0$)

- Solve new distribution of agents:

$$
\begin{aligned}
\dot{\mu}_{ho}(a) &= \gamma_b(a)\,\mu_{hn} - \lambda\mu_{ho}(a) \text{ for } a < a_{ho}^{**}, \\
\dot{\mu}_{lo}(a) &= \lambda 1\left(a < a_{ho}^{**}\right)\mu_{ho}(a) - \gamma_s 1\left(a < a_l^{**}\right)\mu_{lo}(a) \text{ for } a < T, \\
\dot{\mu}_{hn} &= (\mu - x) + \mu_{ho}\left(a_{ho}^{**}\right) - \lambda\mu_{hn} - \mu_{hn}\int_0^{a_l^{**}} \gamma_b(a)\,da,
\end{aligned}
$$

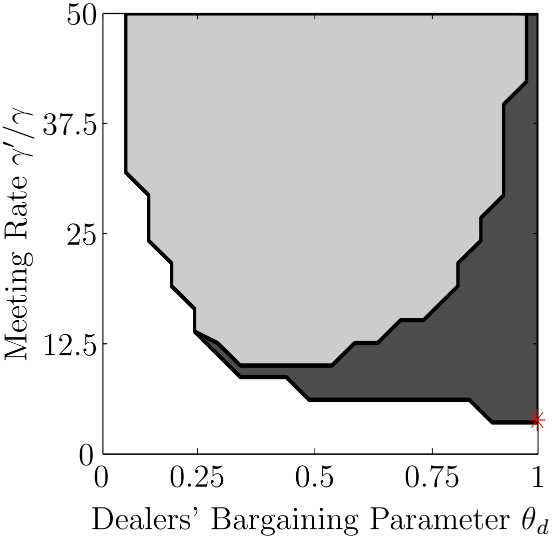
- New cutoff ages, trading rates, and prices $p^{nd}(a)$.

Counterfactual 2: No dealers ($\gamma' = 0$)

	Estimated Model	No Dealer Market
$\int_0^T \mu_{lo}(a)\,da + \int_0^{a^*_{do}} \mu_{do}(a)\,da$	1,681 [1,646; 2,399]	2,013 [1,979; 2,634]
$\frac{\int_0^T \mu_{lo}(a)da + \int_0^{a^*_{do}} \mu_{do}(a)da}{A}$	0.183 [0.179; 0.256]	0.206 [0.203; 0.270]
$\int_0^{a^*_l} \mu_{lo}(a)\,da + \int_0^{a^*_{do}} \mu_{do}(a)\,da$	1,215 [1,202; 1,755]	2,000 [1,979; 2,616]
$\frac{\int_0^{a^*_l} \mu_{lo}(a)da + \int_0^{a^*_{do}} \mu_{do}(a)da}{A}$	0.132 [0.130; 0.187]	0.205 [0.203; 0.268]
$p(0)$	17,611,151 $[17,253; 17,969] * 10^3$	18,118,803 $[17,791; 18,738] * 10^3$
$p(10)$	8,437,910 $[8,366; 8,531] * 10^3$	9,086,250 $[8,836; 9,295] * 10^3$
Allocations	$2.054 * 10^9$ $[1.942; 2.060] * 10^9$	$1.984 * 10^9$ $[1.859; 1.990] * 10^9$
Search Costs	$6.534 * 10^6$ $[4.817; 14.182] * 10^6$	$7.817 * 10^6$ $[5.631; 16.368] * 10^6$
Dealers Costs	$244 * 10^6$ $[232.8; 303.1] * 10^6$	0 [0; 0]
Welfare	$1.802 * 10^9$ $[1.614; 1.803] * 10^9$	$1.977 * 10^9$ $[1.844; 1.983] * 10^9$

- Dealers improve allocations but decrease welfare, as their operations are costly and they impose a negative externality by lowering other agents' meeting rates.
- Worse allocation but higher prices with no dealers.

When do dealers decrease welfare?



Conclusions:

- I construct a model of a decentralized asset market to investigate the effect of trading frictions on asset allocations and asset prices.

- Model has some limitations:
  - Mass of new assets is exogenous.
  - No aggregate shocks.
  - No information on buyers. Trading frictions only from sellers' side.
  - Limited heterogeneity of agents and dealers.

- Nonetheless, framework useful to empirically analyze decentralized asset markets:
  - Characterization of an asset market in equilibrium.
  - Estimation is relatively simple.
  - Perform counterfactuals.