META4
18/March/2016

Auction Theory meets General Equilibrium Effects

Solving a Vickrey Auction embedded in an Exchange Economy

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Outline

- Motivation
- Base Assumptions
- Exchange Economy
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  - Existence and Uniqueness of Equilibrium
- The $(L = 1 + K = 1)$ goods case
  - The model
- The $(L \geq 1 + K = 1)$ goods case
  - The model
- Set-ups of interest – when will GE effects come into play?
- Solving the Vickrey Auction
  - Simplifying assumption
- Winner's Curse and Efficiency – Dropping the simplifying assumption
- Discussion and Other applications

Motivation

- The theory has been developed around partial equilibrium analysis
  - Quasilinear preferences on wealth
- Only recently have income effects been taken into consideration
  - (Saitoh & Serizawa 2008); (Sakai 2008); (Dastidar 2015);
- Even so, they present only the numeraire as an outside good
- Auctioned goods' values and budget constraints are exogenously imposed
- A new benchmark model
  - A "well behaved" auction – Vickrey Auction (VA) – (Vickrey 1961)
  - With "well behaved" preferences
  - Allowing for General Equilibrium Effects (GEE) to appear

Base Assumptions

- Preferences represented by utility functions that are, unless otherwise specified:
  - Continuous
  - Smooth
  - Smoothly monotone
  - Smoothly quasiconcave
  - Bounded from below
- Goods are always Normal and Gross Substitutes
- All divisible goods are essential for positive utility, but not the auctioned good
- Outside goods $(x_l,\ l \in L)$ are divisible, but auctioned good (K) is indivisible
- Agents have strictly positive endowments of every divisible good $(\boldsymbol{\omega}_{-K} \gg \mathbf{0})$
- Non-cooperative behaviour

- Imply that Demand Functions are:
  - Homogenous of Degree 0
  - Smooth
  - Possess a Smooth inverse
  - Bounded from below
  - Satisfy Walra's Law
  - Satisfy Desirability
  - ND and Symmetry of Slutsky matrix

$$u_i = f(\boldsymbol{x}_{l_i}, K_i)$$

Exchange Economy

Introducing a new good

$$
\begin{array}{ccccc}
Z_0 & & K_i, p_K & \rightarrow & Z_1 \\
\downarrow & & \uparrow & & \downarrow \\
\boldsymbol{p}_{\boldsymbol{L},\mathbf{0}}^{\boldsymbol{N}} & \rightarrow & (VA) & & \boldsymbol{p}_{\boldsymbol{L},\mathbf{1}}^{\boldsymbol{N}}
\end{array}
$$

- $p_{L,0}^N = p_{L,1}^N$?
  - ➢ *Always* equal
  - ➢ *Not always* equal

Existence and Uniqueness of Equilibrium

- **IF** Base Assumptions ⇒ Existence and Uniqueness when K is ***not*** traded
  - ➢ Never optimal to bid total *non*-K wealth**
  - ➢ Since non-K goods are divisible, the buyer can always find a combination of endowments such that $(\boldsymbol{\omega}_{-\boldsymbol{K}} - \widehat{\boldsymbol{\omega}_{-\boldsymbol{K}}} \gg \mathbf{0})$
- **THEN** Base Assumptions ⇒ Existence and Uniqueness when K is traded

The $(L = 1 + K = 1)$ goods case

The Model

- $n \geq 3$ agents – including the seller
- $u_i = f_i(x_{1,i}, K_i)$ with:
  - $x_{1,i} > 0 \Leftrightarrow u_i > 0$
  - $x_{1,i} = 0 \Leftrightarrow u_i = 0$
- With Budget Constraint: $p_{1,t} * \left(x_{1,i} - \omega_{1,i}\right) + p_{K,t} * \left(K_i - \omega_{K,i}\right) \leq 0$
- $\omega_{K,i} = \begin{cases} 1, & i = s \\ 0, & otherwise \end{cases}$ and $\boldsymbol{\omega_1} \gg \mathbf{0}$
- For $i = 1, \dots, n$ and later re-labelled accordingly as seller (s), non-buyers ($nb_1, \dots, nb_j$) and buyer (b) if the winner is different from the seller;
- Demand for K not capped at unity, but limited supply

The $(L = 1 + K = 1)$ goods case

- Find:
  - $x^{*}_{1,i}$ given $(K_i = 0)$
  - $x^{**}_{1,i}$ given $(K_i = 1)$
- Set $K_i = \omega_{K,i}$: no trade on K

Before the Auction

- $$Z_0 = \begin{pmatrix} \frac{p_{1,0}\omega_{1,nb1} - p_{K,0}(0-0)}{p_{1,0}} - \omega_{1,nb1} & 0 \\ \vdots & \vdots \\ \frac{p_{1,0}\omega_{1,nb(n-1)} - p_{K,0}(0-0)}{p_{1,0}} - \omega_{1,nb(n-1)} & 0 \\ \frac{p_{1,0}\omega_{1,s} - p_{K,0}(1-1)}{p_{1,0}} - \omega_{1,s} & 1-1 \end{pmatrix}$$

- $z_{1,0}(p_{1,0}) = \sum_{i=1}^{n} \frac{p_{1,0}\omega_{1,i}}{p_{1,0}} - \sum_{i=1}^{n} \omega_{1,i} = 0$
  - No-trade equilibrium
  - $p^{N}_{1,0} = 1$

- Find:
  - $x^{*}_{1,i}$ given $(K_i = 0)$
  - $x^{**}_{1,i}$ given $(K_i = 1)$
- Set $K_b = 1, K_{-b} = 0$

After the Auction

- $$Z_1 = \begin{pmatrix} \frac{p_{1,1}\omega_{1,b} - p_{K,0}(1-0)}{p_{1,1}} - \omega_{1,b} & 1 \\ \vdots & \vdots \\ \frac{p_{1,1}\omega_{1,nb(n-2)} - p_{K,0}(0-0)}{p_{1,1}} - \omega_{1,nb(n-2)} & 0 \\ \frac{p_{1,1}\omega_{1,s} - p_{K,0}(0-1)}{p_{1,1}} - \omega_{1,s} & -1 \end{pmatrix}$$

- $z_{1,1}(p_{1,1}) = \frac{p_{K,0}*1}{p_{1,1}} - \frac{p_{K,0}*1}{p_{1,1}} = 0$
  - No-trade equilibrium: +transfer - transfer
  - $p^{N}_{1,1} = 1$

The $(L \geq 1 + K = 1)$ goods case

The Model

- $n \geq 3$ agents – including the seller
- $u_i = f_i(\boldsymbol{x}_{\boldsymbol{L},\boldsymbol{i}}, K_i)$ with:
  - $x_{l,i} > 0 \Leftrightarrow u_i > 0, \forall l \in L$
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- $\omega_{K,i} = \begin{cases} 1, & i = s \\ 0, & otherwise \end{cases}$ and $\boldsymbol{\omega}_{-\boldsymbol{K}} \gg \boldsymbol{0}$
- For $i = 1, \ldots, n$ and later re-labelled accordingly as seller (s), non-buyers ($nb_1, \ldots, nb_j$) and buyer (b) if the winner is different from the seller;
- Demand for K not capped at unity, but limited supply

The $(L \geq 1 + K = 1)$ goods case

Before the Auction

$$Z_0 = \begin{pmatrix} x^*_{1,nb1}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_{nb1}}) - \omega_{1,nb1} & x^*_{2,nb1}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_{nb1}}) - \omega_{2,nb1} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ x^*_{1,nb(n-1)}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_{nb(n-1)}}) - \omega_{1,nb(n-1)} & x^*_{2,nb(n-1)}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_{nb(n-1)}}) - \omega_{2,nb(n-1)} & \cdots & 0 \\ x^{**}_{1,s}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_s}) - \omega_{1,s} & x^{**}_{2,s}(\boldsymbol{p_{L,0}}, \boldsymbol{\omega_s}) - \omega_{2,s} & \cdots & 1-1 \end{pmatrix}$$

- $$\begin{cases} z_{1,0}(\boldsymbol{p^N_{L,0}}) = 0 \\ \vdots \\ z_{L-1,0}(\boldsymbol{p^N_{L,0}}) = 0 \end{cases}$$

After the Auction

$$Z_1 = \begin{pmatrix} x^{**}_{1,b}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_b}) - \omega_{1,b} & x^{**}_{2,b}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_b}) - \omega_{2,b} & \cdots & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x^*_{1,nb(n-1)}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_{nb(n-1)}}) - \omega_{1,nb(n-1)} & x^*_{2,nb(n-1)}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_{nb(n-1)}}) - \omega_{2,nb(n-1)} & \cdots & 0 \\ x^*_{1,s}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_s}) - \omega_{1,s} & x^*_{2,s}(\boldsymbol{p_{L,1}}, \boldsymbol{\omega_s}) - \omega_{2,s} & \cdots & -1 \end{pmatrix}$$

- $$\begin{cases} z_{1,1}(\boldsymbol{p^N_{L,1}}) = 0 \\ \vdots \\ z_{L-1,1}(\boldsymbol{p^N_{L,1}}) = 0 \end{cases}$$

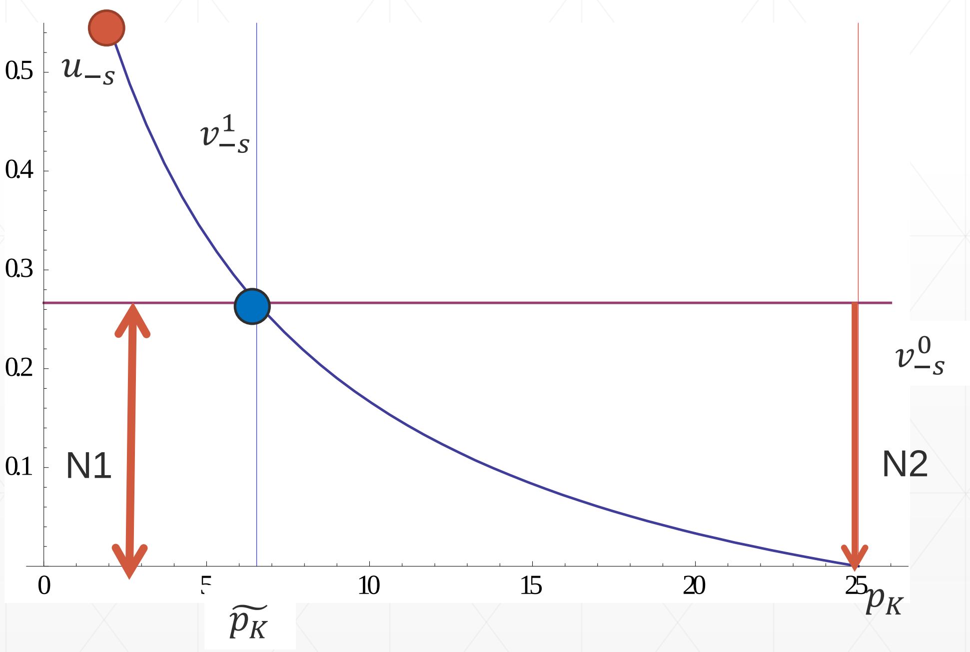
Set-ups of Interest

- Seller participates, but does not conduct the auction
  - Fear of cheating?
  - Reserve price?
  - **Not always the winner**
- $(L \geq 1 + K = 1)$ goods case
- Non-Quasilinear utility on divisible goods
  - Quasilinearity makes all divisible goods perfect substitutes. Existence in divisible goods' markets is no longer assured.
  - Quasilinearity on wealth reduces the model to the $(L = 1 + K = 1)$ goods case
- Heterogeneous agents
  - If the seller has the same preferences/endowments as everyone else, no auction
  - All bidders the same: only ties
  - **Sellers preferences identical to buyer's preferences: transfer from auction never affects Aggregate Demand for divisible goods**

Always $p^N_{L,0} = p^N_{L,1}$	NOT always $p^N_{L,0} = p^N_{L,1}$
• Seller is ALWAYS the winner	• Seller NOT ALWAYS the winner
• $(L = 1 + K = 1)$ goods case	• $(L > 1 + K = 1)$ goods case
• Quasilinear preferences on wealth	• Non-quasilinear preferences on wealth
• Homogeneous agents	• Heterogeneous agents
• NO GEE	• Possible GEE

Solving the VA
Incremental Pay-off Function

- More general case (NOT necessarily $p_{L,0}^{N} = p_{L,1}^{N}$)
- But under the simplifying assumption $\boldsymbol{E}\left[\boldsymbol{p}_{L,1}^{N}\right] = \boldsymbol{p}_{L,0}^{N}$
  - Divisible goods' Market is deep
  - Best guess
- Then, find **indirect utility functions** for $K_i = 0$ and $K_i = 1$, respectively v_i^0 and v_i^1
  - For Non-sellers



N1. $u_i, v_i = 0 \Leftrightarrow some\ x_l = 0$. Then, utility given no consumption of K: $v^0_{-s}(p_K) > 0$; and $\frac{\partial v^0_{-s}}{\partial p_K} = 0$

N2. Buying K for exactly its non-K wealth, will leave no budget for any essential goods, bringing utility to zero

$$p_{K,BC-s} = \boldsymbol{p}_{\boldsymbol{L},\boldsymbol{0}} * \boldsymbol{\omega}_{-\boldsymbol{K},-\boldsymbol{s}} \Longrightarrow v_s^1(p_{K,BC-s}) = 0 < v_s^0(p_{K,BCs})$$

N3a. $\mathbf{x}_L$ are normal, so $\frac{\partial v^1_{-s}}{\partial p_K} < 0$

N3b. At $p_K = 0$, the buyer consumes K for free; thus, $v^1_{-s}(0) \geq v^0_{-s}(0)$

N4. Hence, by applying the Intermediate Value Theorem, $\exists\ \widetilde{p_{K_s}} \in \left[\underline{p_K}, p_{K,BCs}\right), s.t. \mathcal{V}_{-s}(\widetilde{p_{K_s}}) = 0$, where $\boldsymbol{\mathcal{V}}_{-s} = \boldsymbol{v}_i^1 - \boldsymbol{v}_i^0$

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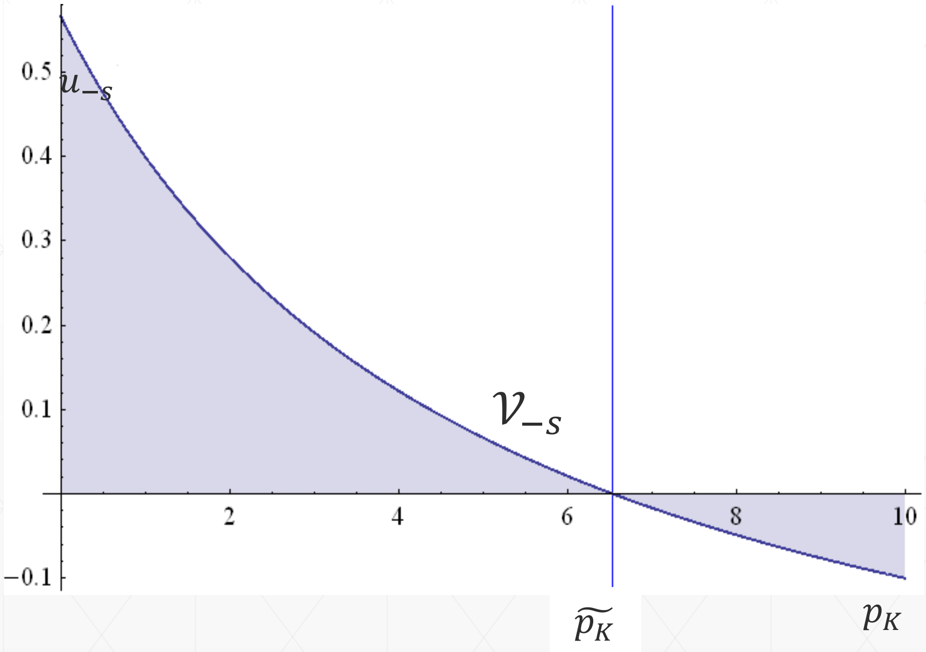

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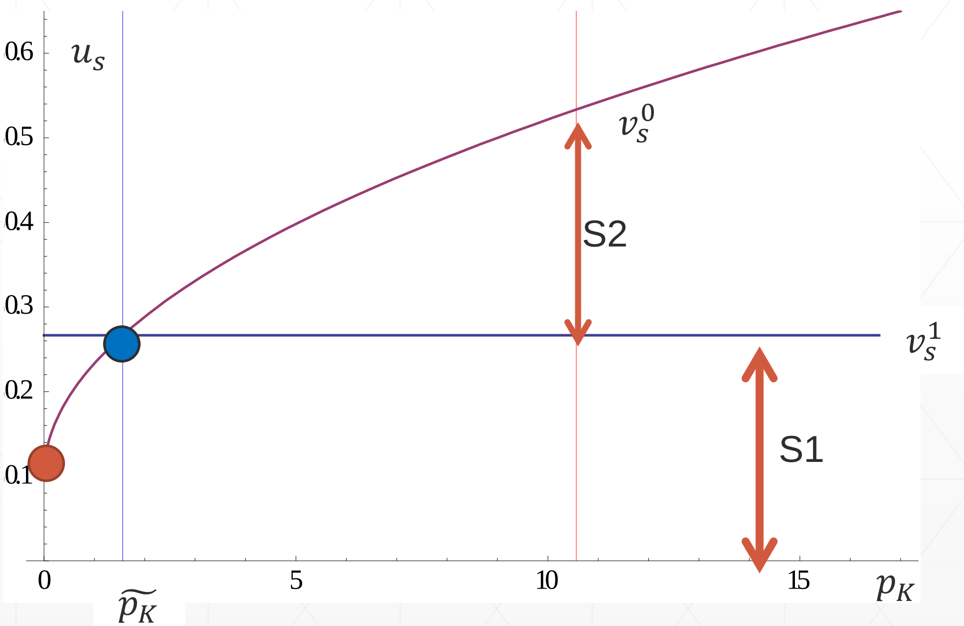

S1. $u_i, v_i = 0 \Leftrightarrow some\ x_l = 0$. Then, upon utility maximization given consumption of K, the utility level must be: $v_s^1(p_K) > 0$; and $\frac{\partial v_s^1}{\partial p_K} = 0$

S2. Selling K for exactly its non-K wealth, the seller would have twice as much non-K wealth at initial price levels to spend on the normal divisible goods; Therefore, at:

$$p_{K,BCs} = \boldsymbol{p_{L,0}} * \boldsymbol{\omega_{-K,s}} \Longrightarrow v_s^1(p_{K,BCs}) < v_s^0(p_{K,BCs})$$

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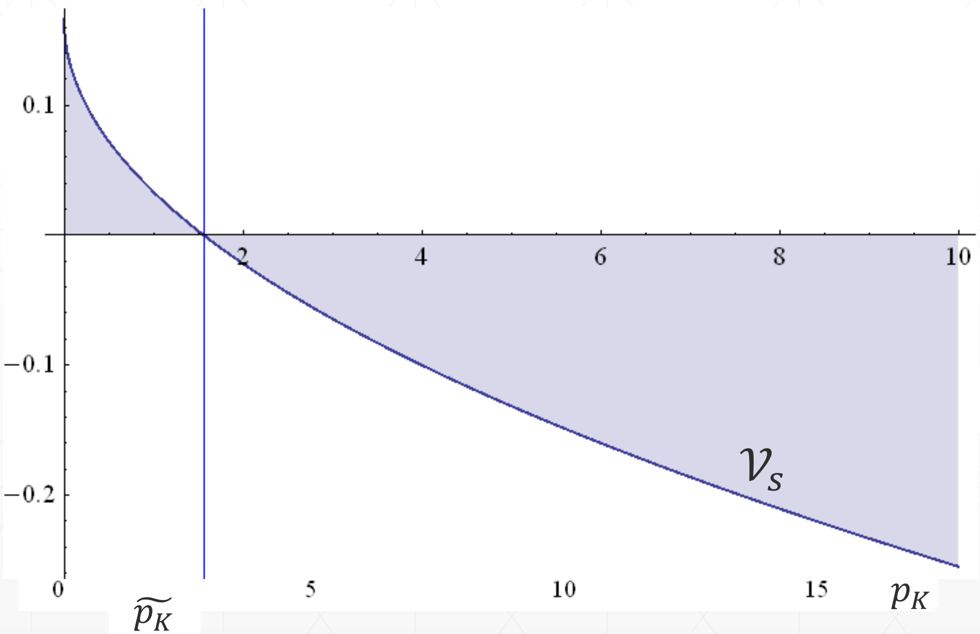

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Solving the VA

Expected Incremental Pay-off Function

- $\mathcal{V}_i$ is the Incremental pay-off function (IPF) and has a similar shape for sellers and non-sellers, ***conditional on winning***

- If the agent does not consume K, then the incremental pay-off is, by definition, zero.

- The Expected Value of Incremental Pay-off for the VA will be:
  - Sum of the value of the IPF at a point $\widehat{p_K}$, or $\mathcal{V}_i(\widehat{p_K})$,times the probability the second highest bid takes exactly that value, $P[\widehat{p_K} = X_n(\widehat{p_{K_{-i}}})]$, for all possible values of p_K from zero up to $\widehat{p_{K_i}}$

    +

  - **ZERO** times the probability the second highest bid is some value above $\widehat{p_{K_i}}$, for all values from $\widehat{p_{K_i}}$ onwards

$$\underset{\widehat{p_{K_i}}}{\operatorname{argmax}}\left(E\left[\mathcal{V}_i(p_K)\,\middle|\,p_K \le \widehat{p_{K_i}}\right] + E\left[\mathcal{V}_i(p_K)\,\middle|\,p_K > \widehat{p_{K_i}}\right]\right)$$

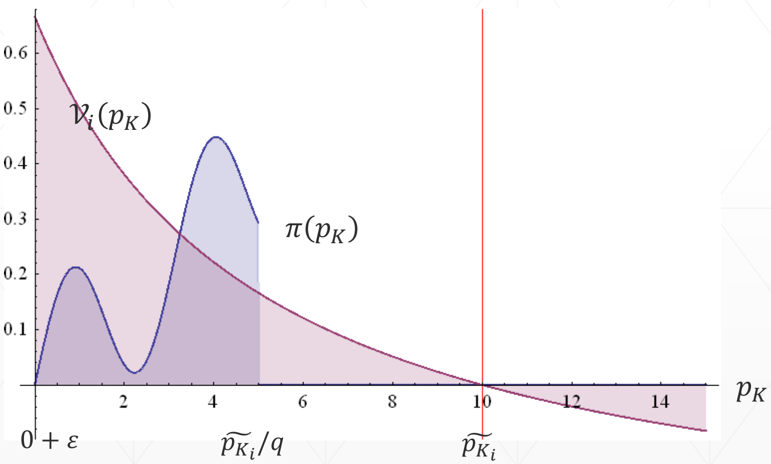
$$\underset{\widehat{p_{K_i}}}{\operatorname{argmax}}\left(\int_0^{\widehat{p_{K_i}}} \left(\mathcal{V}_i(p_K)\cdot\pi(p_K)\right) * dp_K + \int_{\widehat{p_{K_i}}}^{+\infty} \left(0\cdot\pi(p_K)\right) * dp_K\right)$$

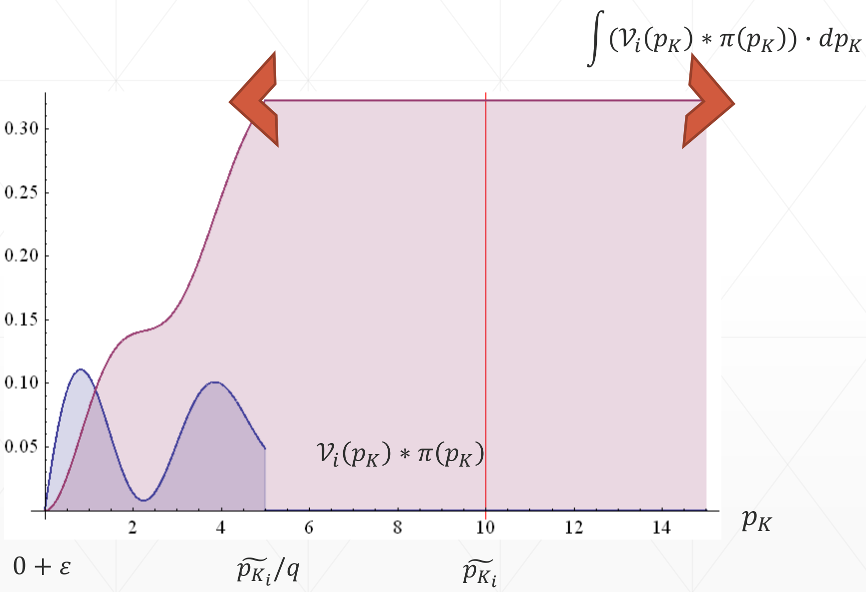
Solving the VA
Expected Incremental Pay-off Function

- THEOREM:

  Agent i's "true value", $\widetilde{p_{K_i}}$, always belongs to the set of values that maximize the Expected IPF, irrespective of the shape of the $p.d.f.\left(\widehat{p_{K_{-i}}}\right)$;

  Hence, bidding one's true value is a weakly dominant strategy, or $\sigma\left(\widetilde{p_{K_i}}\right) \geq \sigma\left(\widehat{p_{K_i}}\right)$





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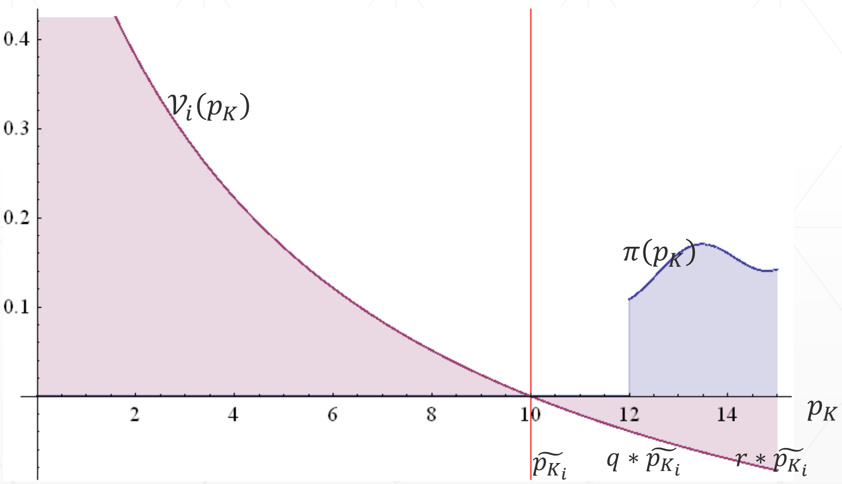

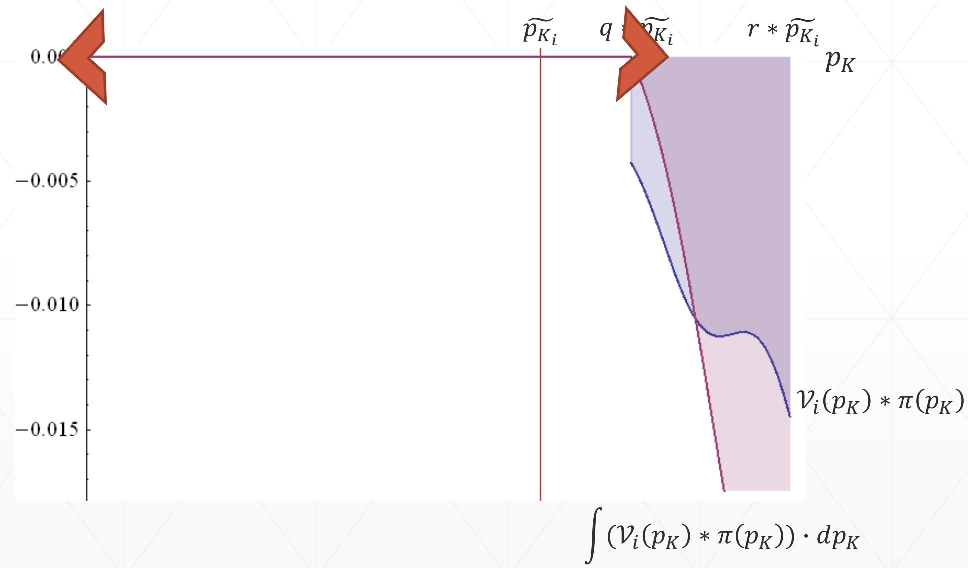

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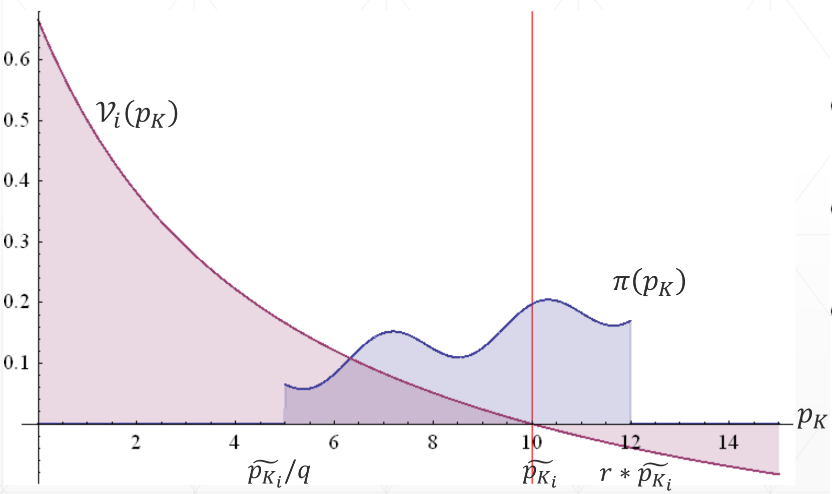
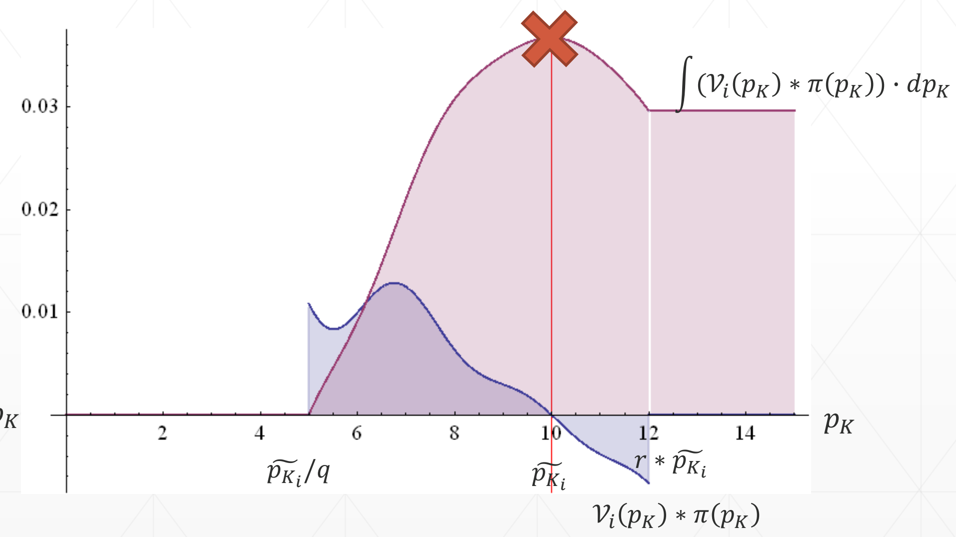




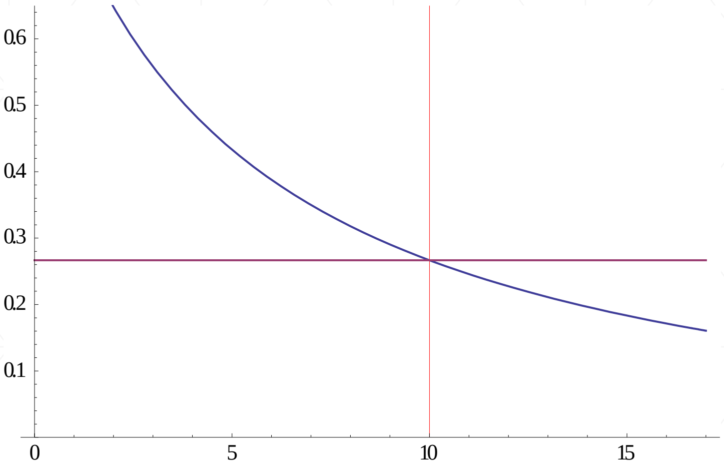
Winner's curse and Efficiency

Dropping the simplifying assumption

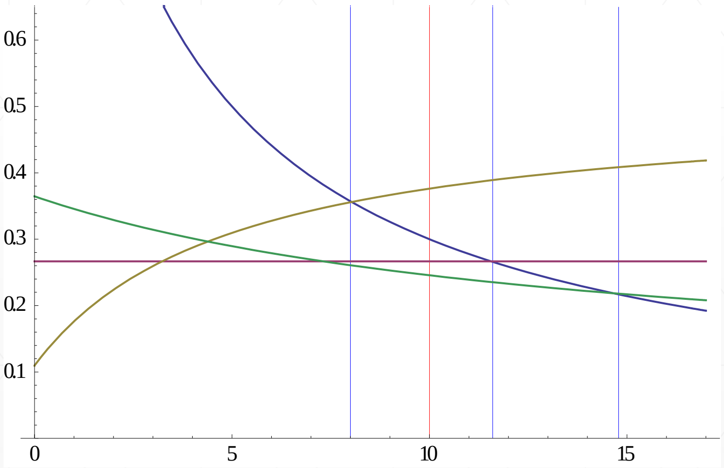
- "True value" is conditional on agent's expectations regarding final price levels
  - $v_i^1(E_0[\boldsymbol{p}_{L,1}^N], p_{K,0}),\ v_i^0(E_0[\boldsymbol{p}_{L,1}^N], p_{K,0})$
  - Maximum feasible bid is still conditional on initial price levels
- Winner's curse MIGHT happen in case $\boldsymbol{p}_{L,1}^N \neq \boldsymbol{p}_{L,0}^N$
  - $v_b^1(\boldsymbol{p}_{L,1}^N, p_{K,0}) < v_b^1(E_0[\boldsymbol{p}_{L,1}^N], p_{K,0})$
  - Or, under simplifying assumption: $v_b^1(\boldsymbol{p}_{L,1}^N, p_{K,0}) < v_b^1(\boldsymbol{p}_{L,0}^N, p_{K,0})$
- It can only truly be avoided if agents were able to account for how different prices and allocations would affect the aggregate demand for divisible goods
- Perfect foresight?
  - $v_i^1\left(E_t[\boldsymbol{p}_{L,1}^N(p_K)]\Big|_{i\ wins}, p_K\right), v_{i,j}^0\left(E_t[\boldsymbol{p}_{L,1}^N(p_K)]\Big|_{j\ \neq\ i\ wins}, p_K\right)$
  - $\mathcal{V}_{i,j}^{-1}(0)$ could now be a set

Winner's curse and Efficiency
Dropping the simplifying assumption

- Perfect foresight:
  - An adjusted v_i^1 - expected change in prices given i wins
  - A set of up to $(n-1)$ curves $v_{i,j}^0$ - expected change in prices given j wins
  - **Tying bids can escape foresight!**



- Which true value?
  - Infimum of the set to avoid a negative pay-off?
  - Attach subjective probabilities to each outcome?
  - Modify the auction in a way so that lowest bidders are eliminated?



Winner's curse and Efficiency
Dropping the simplifying assumption

- How to assess whether the allocation has been efficient?
  - ➢ If prices remain the same: *Efficient*
  - ➢ If prices change, valuations may change ex-post: is the allocation stable?
    - Indirect verification: (Harstad, 2011) hypothetical costless aftermarket
    - New endowment matrix $(\Omega_a) \equiv (A_1)$ latest allocation matrix
    - ***aVA*** keeping the same expectations' formation assumptions
    - Would K change hands?
      - YES: VA is ex-post *Inefficient – but the hypothetical transaction may not be Pareto improving for the whole economy! This would indicate that the current allocation is Pareto optimal*
      - NO: VA is ex-post *Efficient*

- VA no longer, necessarily, efficient
  - ➢ Values become interdependent through income/substitution effects
  - ➢ "Common value" vs "Private value" may be inadequate concepts

Discussion and Other applications

- Solving auctions by finding the Expected Incremental Pay-off functions and their pre-images will yield “true values” conditional on expectations
- It allows to revisit Auction Theory in a more general setting, and it nests traditional outcomes when GEE are not present
- This is a first step to modelling more complex auction rules and scenarios, such as:
  - Asymmetric equilibria
  - Uncertain value, conditional on different states of the world
  - “Background risk”
  - Competition-dependent valuations
  - Analysing the shocks to expectations and risk attitude etc.
- Because it incorporates value theory, exogenously imposed valuations, “common values” and budget constraints can be revisited

Questions?

- Motivation
- Base Assumptions
- Exchange Economy
  - Effect of an Auction
  - Existence and Uniqueness of Equilibrium
- The $(L = 1 + K = 1)$ goods case
  - The model
- The $(L \geq 1 + K = 1)$ goods case
  - The model
- Set-ups of interest – when will GE effects come into play?
- Solving the Vickrey Auction
  - Simplifying assumption
- Winner's Curse and Efficiency – Dropping the simplifying assumption
- Discussion and Other applications

Thank you!