ONLINE APPENDIX TO
"ETHNIC DIVISIONS AND PRODUCTION IN FIRMS"

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1 The Shape of the Production Function

In order to correctly interpret observed ethnic diversity effects, it is useful to first investigate the shape of the production function. I follow an approach comparable to that in Mas and Moretti (2009). Using only homogeneous team observations, processor p's output $q_{p,d}$ is regressed on indicator variables for processor p being worker i, supplier s worker k, and other processor o worker j, on date d:

$$q_{p,d} = \alpha_i^{p\prime} D_{i,d}^p + \beta_j^\prime D_{j,d}^o + \alpha_k^{s\prime} D_{k,d}^s + \varepsilon_{p,d} \tag{1}$$

where $D_{i,d}^p = 1$ if $p = i$ on date d ($D_{j,d}^o$ and $D_{k,d}^s$ are defined analogously). $\widehat{\alpha}_i^p$ then provides an estimate of i's "permanent productivity" as processor and $\widehat{\alpha}_i^s$ as supplier.[1] Focusing on homogeneous teams during the first year of the sample period, Appendix Figure 3 non-parametrically depicts how average processor output varies with (a) processor permanent productivity (across the x-axis), (b) supplier permanent productivity (across the plot lines), and (c) other processor permanent productivity (across panel A and B).[2]

2 Magnitude of the Increase in Taste for Discrimination during Conflict

By how much did suppliers' weight on the utility of non-coethnic downstream workers fall when conflict began? A limitation of studying triangular production units is that I am unable to separately identify the structural parameters θ_C and θ_{NC} because suppliers are never observed working purely for their own benefit. But if the model above holds, I can bound the impact of conflict on θ_{NC} by taking advantage of the plant's worker rotation system. The required assumption is that θ_C was unaffected by conflict, an assumption supported by the fact that average output in homogeneous teams did not change during the conflict period.

[1] Two limitations of this approach should be noted. (1) Ability proxies would ideally be estimated on, say, one half of the data, and then used in second-stage analysis using outcome data from the other half of the data. But because a large T is important in two-stage approaches (Arcidiacono et al., 2011), I estimate the ability proxy using the whole period of data observed. (2) If the exact approach in Mas and Moretti (2009) was followed, $q_{p,d}$ would be regressed on $D_{i,d}^p$ and team dummies. However, in the current setting a team is defined as a specific worker in the supplier position and two other workers in the processor positions. The Mas and Moretti (2009) approach therefore provides no natural way to estimate supplier ability proxies (and only two processors share a given team dummy). I therefore use additive, individual fixed effects.

[2] $\widehat{\alpha}^p$ is normalized to have the mean and standard deviation of processor output, and $\widehat{\alpha}^s$ the mean and standard deviation of team output. Note also that, because all suppliers in a packing hall obtain roses from the same "pool" of flowers arriving from the greenhouses, mechanically negative across-team "peer effects" should in theory be observed: less flowers are left for other teams if a given team is more productive. But such effects should be small for a sample of the size considered here, and other teams of different configurations should not be differentially affected.

Step 1: Ratios. In the Cobb-Douglas model laid out in the appendix, the supplier ability term cancels out if we take the ratio of the two processors' output:

$$\frac{q_1}{q_2} = \left(\frac{\alpha_1}{\alpha_2}\right)^{\frac{2\beta}{2-\beta-2\gamma}} \left(\frac{1+2\theta_1}{1+2\theta_2}\right)^{\frac{2\gamma}{2-\beta-2\gamma}} \tag{2}$$

Step 2: Ratio-of-ratios. Recall that two workers in a team stay put when the third worker is switched for another worker returning from leave. Consider a sample of horizontally mixed teams in which a supplier of processor 1's ethnicity is replaced by a supplier of processor 2's ethnicity (in between dates $d = 0$ and $d = 1$). In the model above, the abilities of the two processors do not influence their relative output under one supplier compared to their relative output under another supplier:

$$\frac{q_{1,d=0}/q_{2,d=0}}{q_{1,d=1}/q_{2,d=1}} = \left(\frac{1+2\theta_C}{1+2\theta_{NC}}\right)^{\frac{4\gamma}{2-\beta-2\gamma}} \tag{3}$$

Taking the ratio of the ratio of processors' output before a supplier switch to the same ratio after the switch can here be thought of as analogous to a difference-in-differences analysis in additive models. We are left with a quantity that depends only on the powers of the output function, and θ_C and θ_{NC}.

Step 3: Ratio-of-ratio-of-ratios. Finally, if θ_C was unaffected by conflict, suppliers' weight on coethnics' utility should have the same influence on the ratio-of-ratios before and after conflict. Taking the ratio of the pre- and during-conflict quantities, we arrive at an expression that relates θ'_{NC}, the weight on non-coethnics' utility after conflict began, to the pre-conflict θ_{NC}:

$$\frac{(q_{1,d=0}/q_{2,d=0})/(q_{1,d=1}/q_{2,d=1})}{(q_{1,d=0'}/q_{2,d=0'})/(q_{1,d=1'}/q_{2,d=1'})} = \left(\frac{1+2\theta_{NC}}{1+2\theta'_{NC}}\right)^{\frac{4\gamma}{2-\beta-2\gamma}} \tag{4}$$

I estimate the ratio-of-ratios on a sample of horizontally mixed teams in which a supplier is followed by another supplier of the other ethnic group. Instead of comparing the change in output from one day to the next, I compare average output under the first supplier, $s = 0$, to average output under the second supplier, $s = 1$. The log of the numerator of the left-hand side of the ratio-of-ratios is regressed on the log of the denominator and a constant:

$$\log(q_{1,\overline{s=0}}/q_{2,\overline{s=0}}) = \lambda + \eta \log(q_{1,\overline{s=1}}/q_{2,\overline{s=1}}) + \varepsilon \tag{5}$$

The resulting $\widehat{\lambda}$ can be interpreted as an estimate of $\log((1+2\theta_1/1+2\theta_2)^{\frac{4\gamma}{2-\beta-2\gamma}})$. Arranging the data such that $\log((1+2\theta_1/1+2\theta_2)^{\frac{4\gamma}{2-\beta-2\gamma}}) = \log((1+2\theta_C/1+2\theta_{NC})^{\frac{4\gamma}{2-\beta-2\gamma}})$ and estimating (5) on pre-conflict data gives $\widehat{\lambda} = 0.27$. $\widehat{\lambda}'$, from estimating (5) on data from the conflict period, is 0.4. Both estimates are significantly greater than zero at the 1% level.

Noting that $\widehat{\theta}_C = \frac{1}{2}\left(\left(\exp(\widehat{\lambda})\right)^{\frac{2-\beta-2\gamma}{4\gamma}}\left(1+2\widehat{\theta}_{NC}\right) - 1\right)$, with $\widehat{\lambda}$ in hand we can evaluate the locus of pairs of utility-weights that can explain the observed change in output when a supplier of one ethnic group replaces a supplier of the other ethnic group. Suppose further that θ_C did not change when conflict began, as the results of Table V suggest. Then,

$$1 = \frac{\widehat{\theta}_C}{\widehat{\theta}'_C} = \frac{\frac{1}{2}\left(\left(\exp(\widehat{\lambda})\right)^{\frac{2-\beta-2\gamma}{4\gamma}}\left(1+2\widehat{\theta}_{NC}\right)-1\right)}{\frac{1}{2}\left(\left(\exp(\widehat{\lambda}')\right)^{\frac{2-\beta-2\gamma}{4\gamma}}\left(1+2\widehat{\theta}'_{NC}\right)-1\right)} \tag{6}$$

which gives

$$\theta'_{NC} = \frac{1}{2}\left(\frac{1+2\widehat{\theta}_{NC}}{\left(\exp(\widehat{\lambda}'-\widehat{\lambda})\right)^{\frac{2-\beta-2\gamma}{4\gamma}}}-1\right) = \frac{1}{2}\left(\frac{1+2\widehat{\theta}_{NC}}{(\exp(0.13))^{\frac{2-\beta-2\gamma}{4\gamma}}}-1\right) \tag{7}$$

In Appendix Figure 6, I plot θ'_{NC} against θ_{NC} for various combinations of β and γ. It is clear from the figure that the decrease in θ_{NC} – or put differently, the increase in taste for discrimination – required to explain the differential decrease in output in mixed teams during conflict is substantial.

3 Optimal Team Assignment Procedure

I briefly describe the procedure used to compute the optimal assignments in Table VII. See Bhattacharya (2009) for a more detailed description and justification of the procedure. The goal is to maximize the total output of a set of workers with multiple discrete characteristics. Discreteness implies a finite number of worker types, which can be combined into a finite number of team types. Output is maximized by choosing the quantities of each type of team that gives the highest total output, subject to the quantities of each worker type available. A solution to such a system is obtained using integer linear programming.

A worker is fully characterized by a collection of three discrete attributes: tribe, productivity tercile as supplier, and productivity tercile as processor. In turn, the set of possible team types is derived from the set of possible worker types. A team consists of one type of worker as supplier, one type of worker as processor 1, and one type of worker as processor 2.

The two processor positions are considered to be equivalent, and thus the number of processor pairs is calculated as two unordered draws with replacement from the pool of possible workers. There are $\binom{18+2-1}{2} = 171$ ways that these two can be chosen. Combining those with the 18 possibilities for the supplier gives 3078 distinct types of teams, if all possible types were to be considered. Those 3078 team types are mapped into 18 output coefficients when assignment is by productivity, and 63 output coefficients when assignment is by both productivity and tribe, as described in the paper.

An output-maximizing assignment is the solution of an integer linear programming problem with the following objective function:

$$\underset{t_1,\ldots,t_{3078}}{\text{Max}}\, Q = \sum_{i=1}^{3078} \overline{Q}_i t_i \tag{8}$$

Each t_i term represents a possible type of team that can be formed from three workers, and $\overline{Q}_i$ is the average output of that type of team.

The maximization of the objective function is constrained by the number of each type of worker that is present at the plant. For each worker type w_j, a constraint equates the number of workers used with the number of workers in the workforce:

$$\begin{aligned}&\sum\{t_i|\text{there is 1 } w_j \text{ worker in } t_i\}\\&+2\sum\{t_i|\text{there are 2 } w_j \text{ workers in } t_i\}\\&+3\sum\{t_i|\text{there are 3 } w_j \text{ workers in } t_i\}=w_j\end{aligned} \tag{9}$$

The result of building these constraints is an 18×3078 matrix equation for which the columns represent team types and the rows worker types.

The optimal assignments in Table VII were obtained by solving these problems using the Gurobi solver.

4 Theoretical Framework Predictions

In addition to the assumptions in section 3, I make the following assumptions. Let $q_p = f(e_{sp}, \alpha_s, e_p, \alpha_p) = (e_p\alpha_p)^\beta(e_{sp}\alpha_s)^\gamma$. β then measures the slope of processor output in processor ability and effort, and γ the slope in supplier ability and effort. The ability terms are assumed to be positive, and q_p concave in processor and supplier effort. q_p is also assumed to display decreasing returns: $0 < \beta < 1$, $0 < \gamma < 1$, $\beta + \gamma < 1$. The processor's effort carries costs $\frac{1}{2}e_1^2$, and the total effort of the supplier $\frac{1}{2}(e_{s1} + e_{s2})^2$. I assume that $\alpha_p > 1$, $\alpha_s > 1$ and $-\frac{1}{2} < \theta_p < \frac{1}{2}$.[3] I also assume that suppliers do not take ethnicity as a signal of ability.

Consider first the processor's problem, focusing here on processor 1 (processor 2's problem is analogous). A processor maximizes her benefit of pay minus her cost of effort:

$$\begin{aligned}&\underset{e_1}{\text{Max}}\ \ 2w(e_1\alpha_1)^\beta(e_{s1}\alpha_s)^\gamma - \frac{1}{2}e_1^2\\&\text{s.t. } e_1 \geq 0\end{aligned} \tag{10}$$

which gives

$$e_1 = \left(2w\beta(e_{s1}\alpha_s)^\gamma\alpha_1^\beta\right)^{\frac{1}{2-\beta}} \tag{11}$$

Processor effort is thus increasing in processor and supplier ability and in the supplier's effort. Note that the processor's effort choice depends on the supplier's weight on her utility only through its influence on her supply of intermediate flowers.

A supplier maximizes her benefit of pay minus her cost of effort plus the additional utility (or disutility) she derives from the well-being of each of the processors:

$$\begin{aligned}&\underset{e_{s1},e_{s2}}{\text{Max}}\ w((e_1\alpha_1)^\beta(e_{s1}\alpha_s)^\gamma + (e_2\alpha_2)^\beta(e_{s2}\alpha_s)^\gamma) - \frac{1}{2}(e_{s1}+e_{s2})^2\\&\qquad + \theta_1\left(2w(e_1\alpha_1)^\beta(e_{s1}\alpha_s)^\gamma - \frac{1}{2}e_1^2\right) + \theta_2\left(2w(e_2\alpha_2)^\beta(e_{s2}\alpha_s)^\gamma - \frac{1}{2}e_2^2\right)\\&\text{s.t. } e_{s1} \geq 0 \text{ and } e_{s2} \geq 0\end{aligned} \tag{12}$$

The supplier's first order condition for e_{s1} gives

$$(e_{s1}+e_{s2}) = (1+2\theta_1)\,w(e_1\alpha_1)^\beta\gamma e_{s1}^{\gamma-1}\alpha_s^\gamma \tag{13}$$

[3]If this restriction is violated corner solutions arise.

When the supplier's two first order conditions hold simultaneously,

$$e_{s1} = \left(\frac{(1+2\theta_1)\, w (e_1\alpha_1)^{\beta} \gamma (\alpha_s)^{\gamma-1}}{1 + \left(\frac{1+2\theta_1}{1+2\theta_2}\right)^{\frac{1}{\gamma-1}} \left(\frac{e_1\alpha_1}{e_2\alpha_2}\right)^{\frac{\beta}{\gamma-1}}} \right)^{\frac{1}{2-\gamma}} \tag{14}$$

Because the supplier considers the pay-off (from own pay and processors' utility) of supply to each of the processors, her effort devoted to supplying processor 1 is increasing in that processor's ability and utility weight, but decreasing in the ability and utility weight of the other processor.

The model has the following predictions. Because tedious algebra is involved, the proofs appear in the next section.

Proposition 1 (Existence and comparative statics):

i. There exists a unique equilibrium in which production is given by

$$q_1^* = \frac{k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_1)^{\frac{2\gamma}{2-\beta-2\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_1)^{\frac{2-\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \tag{15}$$

$$Q^* = \frac{k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_1)^{\frac{2\gamma}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_2)^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_1)^{\frac{2-\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \tag{16}$$

where $k_q = (2\beta)^{\frac{\beta}{2-\gamma-\beta}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}}$ and $Q = q_1 + q_2$ is team output.

ii. Processor output is increasing in own ability, the ability of the supplier and the weight the supplier attaches to her utility, but decreasing in the ability and weight of the other processor: $\frac{\partial q_1}{\partial \alpha_1} > 0$, $\frac{\partial q_1}{\partial \alpha_s} > 0$, $\frac{\partial q_1}{\partial \alpha_2} < 0$, $\frac{\partial q_1}{\partial \theta_1} > 0$, $\frac{\partial q_1}{\partial \theta_2} < 0$

In principle the θ's vary continuously. However, to focus on the possibility of supplier discrimination, I consider a simplified case. Let $\theta_i = \theta_C$ if processor i is of the supplier's ethnic group, and $\theta_i = \theta_{NC}$ if not. Processors are then observed in four different positions: in homogeneous teams (H), in vertically mixed teams (VM), and in horizontally mixed teams in which the processor in question may (HM,C) or may not (HM,NC) be of the supplier's ethnic group. From a team perspective there are three types of ethnicity configurations.

Proposition 2 (Processor output): Processor output is unaffected by the ethnicity of the supplier and the other processor if the supplier has ethnicity-neutral social preferences ($\theta_C = \theta_{NC}$): $q_H = q_{HM,C} = q_{HM,NC} = q_{VM}$. Processor output is higher (a) when working with a coethnic supplier, and (b) when working with another processor who is not of the supplier's ethnicity if the supplier has discriminatory preferences ($\theta_C > \theta_{NC}$): $q_{HM,C} > q_H > q_{VM} > q_{HM,NC}$.

Ethnicity-neutral upstream workers' supply to each processor is determined by the abilities of the three workers. Proposition 2 makes clear that biased supplier preferences will lead to "horizontal misallocation" – the relative supply to the two processors deviating from their relative abilities – in horizontally mixed teams, and to "vertical misallocation" – the total quantity of roses supplied deviating from the ethnicity-neutral optimal supply – in both horizontally and vertically mixed teams. Misallocation of roses is predicted to lower team output:

Proposition 3 (Team output): Team output is unaffected by a team's ethnicity configuration if the supplier has ethnicity-neutral social preferences ($\theta_C = \theta_{NC}$): $Q_H = Q_{HM} = Q_{VM}$. Team output in homogeneous teams is higher than in mixed teams if the supplier has discriminatory preferences ($\theta_C > \theta_{NC}$): $Q_H > Q_{VM}$ and $Q_H > Q_{HM}$

Next I consider the framework's predictions for how upstream capacity is allocated across downstream workers:

Proposition 4 (Supplier ability effect): The effect of supplier ability on processor output is unaffected by a team's ethnicity configuration if the supplier has ethnicity-neutral social preferences ($\theta_C = \theta_{NC}$): $\partial q_H / \partial \alpha_s = \partial q_{HM,C} / \partial \alpha_s = \partial q_{HM,NC} / \partial \alpha_s = \partial q_{VM} / \partial \alpha_s$. Higher supplier ability benefits processor output more (a) when working with a coethnic supplier, and (b) when working with another processor who is not of the supplier's ethnic group if the supplier has discriminatory preferences ($\theta_C > \theta_{NC}$): $\partial q_{HM,C} / \partial \alpha_s > \partial q_H / \partial \alpha_s > \partial q_{VM} / \partial \alpha_s > \partial q_{HM,NC} / \partial \alpha_s$

Biased, higher-ability suppliers allocate more of their additional capacity to supplying coethnic processors because they derive greater benefits from coethnics' output.

It is possible that the period of ethnic conflict in Kenya in early 2008 led to a change in attitudes towards co-workers of the other ethnic group, which I model as a change in θ_{NC}:

Proposition 5 (Change in preferences): A decrease in the weight attached to the well-being of non-coethnics leads to an increase in the output of the processor of the supplier's ethnicity in horizontally mixed teams, no change in the output of processors in homogeneous teams, and a decrease in the output of processors who are not of the supplier's ethnicity. The decrease is greater for non-coethnic processors in horizontally mixed teams: $\partial q_{HM,C} / \partial \theta_{NC} < 0 = \partial q_H / \partial \theta_{NC} \leq \partial q_{VM} / \partial \theta_{NC} \leq \partial q_{HM,NC} / \partial \theta_{NC}$

If the gap between the weight attached to coethnics' and non-coethnics' well-being widens, so does the output gap between teams of different ethnicity configurations.

Six weeks into the conflict period the plant began paying processors for their combined output. Under such a pay system a processor's utility from pay is $w(q_1 + q_2)$, rather than $2wq_1$ as under individual pay. Processor 1's problem becomes:

$$\begin{aligned} &\underset{e_1}{\text{Max}} \;\; w\left((e_1\alpha_1)^\beta (e_{s1}\alpha_s)^\gamma + (e_2\alpha_2)^\beta (e_{s2}\alpha_s)^\gamma\right) - \frac{1}{2}e_1^2 \\ &\text{s.t. } e_1 \geq 0 \end{aligned} \tag{17}$$

which gives

$$e_1 = \left(w\beta(e_{s1}\alpha_s)^\gamma {\alpha_1}^\beta\right)^{\frac{1}{2-\beta}} \tag{18}$$

Under team pay the supplier solves

$$\begin{aligned}\underset{e_{s1},e_{s2}}{\text{Max}}\ & w((e_1\alpha_1)^\beta(e_{s1}\alpha_s)^\gamma+(e_2\alpha_2)^\beta(e_{s2}\alpha_s)^\gamma)-\frac{1}{2}(e_{s1}+e_{s2})^2\\ & +w(\theta_1+\theta_2)((e_1\alpha_1)^\beta(e_{s1}\alpha_s)^\gamma+(e_2\alpha_2)^\beta(e_{s2}\alpha_s)^\gamma)-\theta_1\frac{1}{2}e_1^2-\theta_2\frac{1}{2}e_2^2\\ \text{s.t. } & e_{s1}\geq 0 \text{ and } e_{s2}\geq 0\end{aligned} \tag{19}$$

The supplier's first order condition for e_{s1} gives

$$e_{s1}+e_{s2}=w(1+\theta_1+\theta_2)(e_1\alpha_1)^\beta\gamma(e_{s1}\alpha_s)^{\gamma-1}\alpha_s \tag{20}$$

When the supplier's two first order conditions hold simultaneously,

$$e_{s1}=\left(\frac{w(1+\theta_1+\theta_2)\gamma\,(e_1\alpha_1)^\beta\,\alpha_s^\gamma}{1+\left(\frac{e_2\alpha_2}{e_1\alpha_1}\right)^{\frac{\beta}{1-\gamma}}}\right)^{\frac{1}{2-\gamma}} \tag{21}$$

Because effort devoted to supplying one processor benefits both processors under team pay, the supplier's effort in supplying processor 1 is increasing in both θ_1 and θ_2. If the two processors are of the same ability $e_{s1}=e_{s2}$ under team pay.

Solving the model under team pay gives the following predictions:

Proposition 6 (Team pay):

i. There exists a unique equilibrium under team pay in which production is given by

$$q_1^{TP*}=\frac{k_q^{TP}\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(1+\theta_1+\theta_2)^{\frac{\gamma}{2-\beta-\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \tag{22}$$

$$Q^{TP*}=k_q^{TP}\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}(1+\theta_1+\theta_2)^{\frac{\gamma}{2-\beta-\gamma}} \tag{23}$$

where $k_q^{TP}=\gamma^{\frac{\gamma}{2-\beta-\gamma}}w^{\frac{\beta+\gamma}{2-\beta-\gamma}}\beta^{\frac{\beta+2\gamma}{2-\beta-\gamma}}$.

ii. Output in homogeneous and vertically mixed teams falls when team pay is introduced: $Q_H^{TP}<Q_H$ and $Q_{VM}^{TP}<Q_{VM}$

iii. Output in homogeneous teams will continue to exceed that in vertically mixed teams under team pay if suppliers have discriminatory preferences ($\theta_C>\theta_{NC}$): $Q_H^{TP}>Q_{VM}^{TP}$

iv. The output of the processor of the supplier's ethnicity and the processor who is not of the supplier's ethnicity in horizontally mixed teams is equal under team pay, even if suppliers have ethnic preferences ($\theta_C>\theta_{NC}$): $q_{HM,C}^{TP}=q_{HM,NC}^{TP}$

v. Output in horizontally mixed teams Q_{HM}^{TP} can decrease or increase when team pay is introduced if suppliers have discriminatory preferences ($\theta_C > \theta_{NC}$): $Q_{HM}^{TP} \gtrless Q_{HM}$

In scenarios in which the two downstream workers are of the same ethnic group – homogeneous and vertically mixed teams – the supplier's problem reduces to the same problem she faced under individual pay. In such teams equilibrium production falls under team pay as processors freeride on each other. $Q_H > Q_{VM}$ is expected to continue to hold because biased suppliers' incentive to discriminate against non-coethnics through total supply remains under team pay.

In addition to the negative freeriding effect, team pay is expected to have an offsetting positive effect in horizontally mixed teams, in which $\theta_1 \neq \theta_2$. Because the two processors in a team are paid the same under team pay, the supplier is unable to increase her own utility by "shifting" roses from less to more favored processors. Eliminating horizontal misallocation will positively affect team output.

5 Theoretical Framework Proofs

Proof of proposition 1 (Existence and comparative statics)

Existence.

I show solutions for processor 1, processor 2 is analogous. Processor 1's first order condition gives

$$e_1^* = \left(2w\beta(e_{s1}\alpha_s)^\gamma \alpha_1^\beta\right)^{\frac{1}{2-\beta}}$$

The supplier's first order condition for e_{sp} gives

$$(e_{s1} + e_{s2}) \ = (1+2\theta_1)\, w(e_1\alpha_1)^\beta \gamma e_{s1}^{\gamma-1}\alpha_s^\gamma$$

As $(1+2\theta_1) > 0$, and the other terms in the roots are positive, $e_1^* > 0$ and $e_{s1}^* > 0$, which implies $q_1^* > 0$. Solving gives

$$q_1^* = \frac{k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_1)^{\frac{2\gamma}{2-\beta-2\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_1)^{\frac{2-\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$Q^* = \frac{k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_1)^{\frac{2\gamma}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta_2)^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_1)^{\frac{2-\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

where $k_q = (2\beta)^{\frac{\beta}{2-\gamma-\beta}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}}$ and $Q = q_1 + q_2$ is team output.

Call processor p's utility U_p and supplier s's utility U_s. As

$$\frac{d^2U_p}{de_p^2} \quad = \quad 2w\beta\,(\beta-1)\,\alpha_p^\beta(e_{sp}\alpha_s)^\gamma e_p^{\beta-2} - 1$$

$$\frac{d^2U_s}{de_{sp}^2} = (1+2\theta_p)\, w\gamma\,(\gamma-1)\,\alpha_s^{\gamma}(e_p\alpha_p)^{\beta}e_{sp}^{\gamma-2}-1$$

the second order conditions are globally satisfied as long as output is concave in its arguments, $\beta<1$ and $\gamma<1$.

Comparative statics.

To evaluate the comparative statics of q_1 with respect to α_1, α_s and α_2, it is convenient to rewrite processor 1's output as follows:

$$q_1^* = \frac{k_q\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}\alpha_1^{\frac{2\beta}{2-\beta-\gamma}}(1+2\theta_1)^{\frac{2\gamma}{2-\beta-2\gamma}}}{\left((1+2\theta_1)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\alpha_1^{-\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

As $-\frac{2\beta}{2-2\gamma-\beta}<0$ and $\frac{\gamma}{2-\beta-\gamma}>0$, the denominator decreases when α_1 increases. Moreover, $\frac{2\beta}{2-\beta-\gamma}>0$ so that the numerator increases with α_1. This implies that $\dfrac{\partial q_1}{\partial\alpha_1}>0$.

Similarly, $\frac{2\gamma}{2-\beta-\gamma}>0$ so $\dfrac{\partial q_1}{\partial\alpha_s}>0$.

Finally, $\frac{2\beta}{2-2\gamma-\beta}>0$ and $\frac{\gamma}{2-\beta-\gamma}>0$ imply that $\dfrac{\partial q_1}{\partial\alpha_2}<0$.

To analyze the comparative static of q_1 with respect to θ_1 and θ_2, it is convenient to rewrite processor 1's output as follows:

$$q_1^* = \frac{k_q\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+2\theta_1)^{\frac{\gamma}{2-\beta-\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta_2)^{\frac{2-\beta}{2-2\gamma-\beta}}(1+2\theta_1)^{-\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

As $-\frac{2-\beta}{2-2\gamma-\beta}<0$ and $\frac{\gamma}{2-\beta-\gamma}>0$, the denominator decreases when θ_1 increases. Moreover, $\frac{\gamma}{2-\beta-\gamma}>0$ so that the numerator increases with θ_1. This implies that $\dfrac{\partial q_1}{\partial\theta_1}>0$.

Similarly, $\frac{2-\beta}{2-2\gamma-\beta}>0$ and $\frac{\gamma}{2-\beta-\gamma}>0$, so that $\dfrac{\partial q_1}{\partial\theta_2}<0$.

□

Proof of proposition 2 (Individual output)

With $\tilde\theta_C=\tilde\theta$ as a baseline, express $\tilde\theta_{NC}=c\tilde\theta$,where $c=\frac{\tilde\theta_{NC}}{\tilde\theta_C}$. Replace $(1+2\theta_l)$ with $\widetilde\theta_l$ where $l\in\{C,NC,1,2\}$. Let $\widetilde\theta=\widetilde\theta_{NC}$ and define c to be such that $\widetilde\theta_C=c\widetilde\theta_{NC}=c\widetilde\theta$. Define q_T where $T\in\{H,HM_C,HM_{NC},VM\}$. So for example $q_T=q_H=q(\theta_1=\theta_C,\theta_2=\theta_C)$ if $T=H$. Let

$$\begin{aligned}
A &= K\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(\widetilde\theta)^{\frac{2\gamma}{2-\beta-2\gamma}},\text{ where } K=k_q\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}\\
B &= (\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}\widetilde\theta^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\widetilde\theta^{\frac{2-\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}\\
B' &= (\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}\widetilde\theta^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\widetilde\theta^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}\\
B'' &= (\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}\widetilde\theta^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\left(\frac{\widetilde\theta}{c}\right)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}
\end{aligned}$$

Noting that $\frac{1}{2} > \theta_l > -\frac{1}{2}$ implies $2 > \widetilde{\theta}_l > 0$, $B'' = (\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} \left(\frac{\widetilde{\theta}}{c}\right)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}} > 0$ i.f.f. $\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} \left(\frac{\widetilde{\theta}}{c}\right)^{\frac{2-\beta}{2-\beta-2\gamma}} > 0$, which holds.

Then

$$\begin{aligned}
q_{VM} &= \frac{K\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (\widetilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} = \frac{A}{B'} \\
q_{HM,NC} &= \frac{K\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (\widetilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} = \frac{A}{B} \\
q_{H} &= \frac{K\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\widetilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\widetilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (c\widetilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} = \frac{A}{B'} c^{\frac{2\gamma}{2-\beta-2\gamma} - (\frac{2-\beta}{2-\beta-2\gamma})(\frac{\gamma}{2-\beta-\gamma})} \\
q_{HM,C} &= \frac{K\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\widetilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\widetilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} \widetilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} = \frac{A}{B''} c^{\frac{2\gamma}{2-\beta-2\gamma} - (\frac{2-\beta}{2-\beta-2\gamma})(\frac{\gamma}{2-\beta-\gamma})}
\end{aligned}$$

As $B > B\prime > B'' > 0$ and $c > 1$ we have that $q_{HM,C} > q_H > q_{VM} > q_{HM,NC}$.

$\square$

Proof of proposition 3 (Team output)

Q_H vs Q_{VM} :

$$\begin{aligned}
Q_H &= k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-2\gamma-\beta}{2-\gamma-\beta}} (1+2\theta_C)^{\frac{\gamma}{2-\beta-\gamma}} \\
&> k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-2\gamma-\beta}{2-\gamma-\beta}} (1+2\theta_{NC})^{\frac{\gamma}{2-\beta-\gamma}} = Q_{VM} \\
&\iff \\
\theta_C &> \theta_{NC}
\end{aligned}$$

Q_H vs Q_{HM} :

Let $\tilde{\theta}_C = 1 + 2\theta_C$, $\tilde{\theta}_{NC} = 1 + 2\theta_{NC}$ and $c = \dfrac{\tilde{\theta}_C}{\tilde{\theta}_{NC}}$ (note that $c > 1$). To ease the notation, let $\tilde{\theta}_{NC} = \tilde{\theta}$.

$$\frac{Q_H}{Q_{HM}} = \frac{\left(\dfrac{K(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}})}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)}{\left(\dfrac{K(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \tilde{\theta}^{\frac{2\gamma}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}})}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \tilde{\theta}^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (c\tilde{\theta})^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)}, \text{ where } K = k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}$$

Rearranging terms, canceling out the K's, $\tilde{\theta}$'s and factoring out the common terms $c^{\frac{2\gamma}{2-\beta-2\gamma}}$ and $\dfrac{1}{(c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$,

$$\begin{aligned}
\frac{Q_H}{Q_{HM}} &= c^{\frac{2\gamma}{2-\beta-2\gamma}-\frac{2-\beta}{2-\beta-2\gamma}\frac{\gamma}{2-\beta-\gamma}} \frac{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2\gamma}{2-\beta-2\gamma}})}(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}} \\
&= c^{\frac{\gamma}{2-\beta-\gamma}\left(\frac{2-\beta-2\gamma}{2-\beta-\gamma}+\frac{\gamma}{2-\beta-\gamma}\right)} \frac{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})}(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}} \\
&= c^{\left(\frac{\gamma}{2-\beta-\gamma}\right)^2} \frac{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})}(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}} \\
&> c^{\left(\frac{\gamma}{2-\beta-\gamma}\right)^2} \frac{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})}(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}} \\
&\quad \text{as } \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}} > \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} \\
&= c^{\left(\frac{\gamma}{2-\beta-\gamma}\right)^2} \frac{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} > c^{\left(\frac{\gamma}{2-\beta-\gamma}\right)^2} \\
&\quad \text{as } \frac{\gamma}{2-\beta-\gamma} < \frac{2-\beta}{2-\beta-2\gamma} \text{ implies } \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} > \alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{\gamma}{2-\beta-2\gamma}} \\
&\quad \text{So } \frac{Q_H}{Q_{HM}} > c^{\left(\frac{\gamma}{2-\beta-\gamma}\right)^2} > 1 \text{ and thus } Q_H > Q_{HM}
\end{aligned}$$

Q_{HM} vs Q_{VM} :

The ranking of Q_{HM} and Q_{VM} is ambiguous in general. Consider the case where $\alpha_1 = \alpha_2$ and let α denote the common value for α_1 and α_2. Then

$$\begin{aligned}
\frac{Q_{HM}}{Q_{VM}} &= \frac{\left(\dfrac{K(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_C)^{\frac{2\gamma}{2-\beta-2\gamma}})}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_C)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)}{\left(\dfrac{K(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}})}{(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)} \\
&= \frac{\left(\dfrac{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_C)^{\frac{2\gamma}{2-\beta-2\gamma}}}{((\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+(\tilde\theta_C)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)}{\left(\dfrac{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}}{((\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)} \\
&= \frac{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_C)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}}\left(\frac{(\tilde\theta_{NC})^{-1}}{(\tilde\theta_{NC})^{-1}} * \frac{(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}}{(\tilde\theta_{NC})^{\frac{2-\beta}{2-\beta-2\gamma}}+(\tilde\theta_C)^{\frac{2-\beta}{2-\beta-2\gamma}}}\right)^{\frac{\gamma}{2-\beta-\gamma}} \\
&= \frac{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_C)^{\frac{2\gamma}{2-\beta-2\gamma}}}{\left((\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{-1}(\tilde\theta_C)^{\frac{2-\beta}{2-\beta-2\gamma}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}\left(\frac{1}{(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}+(\tilde\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}
\end{aligned}$$

$$> \frac{(\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}} + (\tilde{\theta}_C)^{\frac{2\gamma}{2-\beta-2\gamma}}}{\left((\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}} + (\tilde{\theta}_C)^{-1}(\tilde{\theta}_C)^{\frac{2-\beta}{2-\beta-2\gamma}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \left(\frac{1}{(\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}} + (\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}$$

$$= \left(\frac{(\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}} + (\tilde{\theta}_C)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}} + (\tilde{\theta}_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}} > 1$$

so $Q_{HM} > Q_{VM}$ if $\alpha_1 = \alpha_2$.

□

Proof of proposition 4 (Supplier ability effect)

Define q_T where $T \in \{H, HM_C, HM_{NC}, VM\}$. So for example $q_T = q_H = q(\theta_1 = \theta_C, \theta_2 = \theta_C)$ if $T = H$. We have that $\partial q_T/\partial\alpha_s = \frac{2\gamma}{2-\beta-2\gamma}\alpha_s^{\frac{\beta-2}{2-\beta-2\gamma}} * q_T$. As shown in proposition 2, $q_{HM,C} > q_H > q_{VM} > q_{HM,NC}$. Thus, $\partial q_{HM,C}/\partial\alpha_s > \partial q_H/\partial\alpha_s > \partial q_{VM}/\partial\alpha_s > \partial q_{HM,NC}/\partial\alpha_s$.

□

Proof of proposition 5 (Change in preferences):

WLOG consider an improvement in attitudes towards non-coethnics. Denote by $\tilde{\theta}'_i$ the new value of $\tilde{\theta}_i$ (where $\tilde{\theta}_i = 1 + 2\theta_i$) . With $\tilde{\theta}_C = \tilde{\theta}$ as a baseline, express $\tilde{\theta}_{NC} = c\tilde{\theta}$,where $c = \frac{\tilde{\theta}_{NC}}{\tilde{\theta}_C}$. Further let $\tilde{\theta}'_{NC} = k\tilde{\theta}_{NC}$, where $k = \frac{\tilde{\theta}'_{NC}}{\tilde{\theta}_{NC}}$.Note that $c < 1$, $k > 1$ and $ck < 1$. (Unlike previous propositions, here we express θ_{NC} in terms of θ_C). Let p designate the processor in question and o the other processor.

We have that

$$q_p = \frac{K(\tilde{\theta}_p)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}\left(\tilde{\theta}_p\right)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}\left(\tilde{\theta}_o\right)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}, \text{ where } K = k_q\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}$$

$$\Delta q_\theta =$$

$$\frac{K(\theta'_p)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(\theta'_p)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(\theta'_o)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{K(\theta_p)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}\theta_p^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}\theta_o^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$= \frac{K(\tilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}{\tilde{\theta}^{\frac{\gamma}{2-\beta-\gamma}}} * \left[\frac{(c'_p)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(c'_p)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(c'_o)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{c_p^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c_p^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c_o^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right]$$

where $c_i = c$ and $c'_i = kc$ if processor i is not of the supplier's ethnic group and $c_i = c'_i = 1$ if processor i is of the supplier's ethnic group. So

$$\frac{\tilde{\theta}^{\frac{\gamma}{2-\beta-\gamma}}}{K(\tilde{\theta})^{\frac{2\gamma}{2-\beta-2\gamma}}}\Delta q_\theta =$$

$$\frac{(c'_p)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(c'_p)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(c'_o)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{c_p^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c_p^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c_o^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$= g(\alpha_p, \alpha_o, T, k).$$

The values for c_i and c'_i are given by the T:

$$g_H = \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} = 0$$

$$g_{VM} = \frac{(kc)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{c^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$= c^{\frac{\gamma}{2-\beta-2\gamma}}\left(k^{\frac{\gamma}{2-\beta-2\gamma}} - 1\right)\left(\frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right) > 0$$

$$g_{HM,C} = \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} < 0$$

$$g_{HM,NC} = \frac{(kc)^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{c^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$= c^{\frac{2\gamma}{2-\beta-2\gamma}}\left(\frac{k^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right) > 0$$

Furthermore,

$$g_{HM,NC} = c^{\frac{2\gamma}{2-\beta-2\gamma}}\left(\frac{k^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)$$

$$< c^{\frac{2\gamma}{2-\beta-2\gamma}}\left(\frac{k^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\right)$$

$$= g_{VM}$$

Because, keeping in mind that $1 > kc > c > 0$, $g_{HM,NC} > 0$, and $g_{VM} > 0$

$$\frac{g_{HM,NC}}{c^{\frac{2\gamma}{2-\beta-2\gamma}}} = \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\frac{k^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$-\frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}\frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}} + \alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$
\begin{aligned}
&> \frac{k^{\frac{2\gamma}{2-\beta-2\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} - \frac{1}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} \\
&= \frac{g_{VM}}{c^{\frac{2\gamma}{2-\beta-2\gamma}}}
\end{aligned}
$$

$$
\text{if } \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} > \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}
$$

$$
\iff \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} > \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}
$$

$$
\iff \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}-d)^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}-D)^{\frac{\gamma}{2-\beta-\gamma}}} > \frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}
$$

where $d = (1-kc)\,\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}$ and $D = (1-c)\,\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}$.

The above inequality holds as $\frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}} > 1$, both d and D are positive and the numerator and denominator of $\frac{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}(kc)^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}{(\alpha_p^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}}+\alpha_o^{\frac{2\beta}{2-\beta-2\gamma}}c^{\frac{2-\beta}{2-\beta-2\gamma}})^{\frac{\gamma}{2-\beta-\gamma}}}$ is positive

So, $g_{HM,NC} > g_{VM}$

Thus $g_{HM,NC} > g_{VM} > g_H > g_{HM,C}$ which implies $\Delta q_{\theta HM,NC} > \Delta q_{\theta VM} > \Delta q_{\theta H} > \Delta q_{\theta HM,C}$.

□

Proof of proposition 6 (Team pay):

i.

Processor 1's first order condition gives

$$
e_1 = \left(w\beta(e_{s1}\alpha_s)^{\gamma}{\alpha_1}^{\beta}\right)^{\frac{1}{2-\beta}}
$$

The supplier's first order condition for e_{s1} gives

$$
e_{s1} + e_{s2} = w(1+\theta_1+\theta_2)(e_1\alpha_1)^{\beta}\gamma(e_{s1}\alpha_s)^{\gamma-1}\alpha_s
$$

Solving gives

$$
q_1^{TP} = \frac{k_q^{TP}\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+\theta_1+\theta_2)^{\frac{\gamma}{2-\beta-\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}
$$

$$
Q^{TP} = k_q^{TP}\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}(1+\theta_1+\theta_2)^{\frac{\gamma}{2-\beta-\gamma}}
$$

where $k_q^{TP} = \gamma^{\frac{\gamma}{2-\beta-\gamma}} w^{\frac{\beta+\gamma}{2-\beta-\gamma}} \beta^{\frac{\beta+2\gamma}{2-\beta-\gamma}}$. As $(1+\theta_1+\theta_2) > 0$ and the other terms in the root are positive, $e_1^* > 0$ and $e_{s1}^* > 0$ which implies $q_1^{TP*} > 0$.

As,

$$\frac{d^2 U_p}{de_p^2} = w\beta\left(\beta-1\right)\alpha_p (e_{sp}\alpha_s)^{\gamma} (e_p\alpha_p)^{\beta-2} - 1$$

$$\frac{d^2 U_s}{de_{sp}^2} = \left(w(1+\theta_1+\theta_2)\right)(e_1\alpha_1)^{\beta} \alpha_s \gamma\left(\gamma-1\right)(e_{s1}\alpha_s)^{\gamma-2} - 1$$

the second order conditions are globally satisfied as long as output is concave in its arguments, $\beta < 1$ and $\gamma < 1$.

ii.

To show that output in homogeneous and vertically mixed teams falls when team pay is introduced, it suffices to show that $Q^{TP} < Q$ when $\theta_1 = \theta_2$. Let $\theta_1 = \theta_2$, and denote their common value by θ. Then:

$$\begin{aligned}
Q^* &= \frac{k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta)^{\frac{2\gamma}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}} (1+2\theta)^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta)^{\frac{2-\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}} (1+2\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \\
&= k_q \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{2\gamma}{2-\beta-2\gamma} - \frac{2-\beta}{2-2\gamma-\beta}\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{1-\frac{\gamma}{2-\beta-\gamma}} \\
&= (2\beta)^{\frac{\beta}{2-\gamma-\beta}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}} \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}
\end{aligned}$$

and

$$\begin{aligned}
Q^{TP*} &= k_q^{TP} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}} + \alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}} (1+\theta+\theta)^{\frac{\gamma}{2-\beta-\gamma}} \\
&= k_q^{TP} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}} \\
&= \beta^{\frac{\beta+2\gamma}{2-\beta-\gamma}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}
\end{aligned}$$

So we have,

$$\begin{aligned}
\frac{Q^*}{Q^{TP*}} &= \frac{(2\beta)^{\frac{\beta}{2-\gamma-\beta}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}} \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}}{\beta^{\frac{\beta+2\gamma}{2-\beta-\gamma}} w^{\frac{\beta+\gamma}{2-\gamma-\beta}} \gamma^{\frac{\gamma}{2-\gamma-\beta}} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}} (1+2\theta)^{\frac{\gamma}{2-\beta-\gamma}} \left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}} + \alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}} \\
&= \frac{(2\beta)^{\frac{\beta}{2-\gamma-\beta}} \alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}}{\beta^{\frac{\beta+2\gamma}{2-\beta-\gamma}} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}}} = \frac{2^{\frac{\beta}{2-\gamma-\beta}} \alpha_s^{\frac{\gamma}{2-\beta-\gamma}}}{\beta^{\frac{2\gamma}{2-\beta-\gamma}}} \\
&= \alpha_s^{\frac{\gamma}{2-\beta-\gamma}} \left(\frac{2^{\beta}}{\beta^{2\gamma}}\right)^{\frac{1}{2-\gamma-\beta}} > \alpha_s^{\frac{\gamma}{2-\beta-\gamma}}
\end{aligned}$$

As it was assumed that $\alpha_s > 1$ we have $Q^* > Q^{TP*}$ in homogeneous and vertically mixed teams.

iii.

$$\begin{aligned} Q_H^{TP} &= k_q^{TP}\alpha_s^{\frac{2-\beta+4\gamma-\gamma\beta}{2-\beta}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}(1+2\theta_C)^{\frac{\gamma}{2-\beta-\gamma}} \\ &> k_q^{TP}\alpha_s^{\frac{2-\beta+4\gamma-\gamma\beta}{2-\beta}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}(1+2\theta_{NC})^{\frac{\gamma}{2-\beta-\gamma}} = Q_{VM}^{TP} \\ &\iff \theta_C > \theta_{NC} \end{aligned}$$

iv.

To show that $q_{HM,C}^{TP} = q_{HM,NC}^{TP}$, it suffices to show that in horizontally mixed teams, we have that individual output is invariant to that individual's ethnicity. To that effect we observe that the utility-weights enter in the expression for individual output,

$$q_1^{TP} = \frac{k_q^{TP}\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+\theta_1+\theta_2)^{\frac{\gamma}{2-\beta-\gamma}}}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

through the sum $(1+\theta_1+\theta_2)$, which is invariant to the whether processor 1 is the coethnic individual in the team.

v.

Let $\theta_{NC} = \theta$ and $\theta_C = c(\theta_{NC}) = c\theta$. We have that

$$\begin{aligned} &\left(Q_{HM}^{TP} - Q_{HM}\right) \\ = \; & k_q^{TP}\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}\right)^{\frac{2-\beta-2\gamma}{2-\beta-\gamma}}(1+\theta_C+\theta_{NC})^{\frac{\gamma}{2-\beta-\gamma}} \\ & -\frac{k_q\alpha_s^{\frac{2\gamma}{2-\beta-\gamma}}\left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+2\theta_C)^{\frac{2\gamma}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(1+2\theta_{NC})^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta_C)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta_{NC})^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}} \\ = \; & k_q\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\left[\frac{\left(\frac{2^\beta}{\beta^{2\gamma}}\right)^{\frac{1}{2-\gamma-\beta}}\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2\gamma}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2\gamma}{2-2\gamma-\beta}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}\right. \\ & \left.-\frac{\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}\left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+2c\theta)^{\frac{2\gamma}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(1+2\theta)^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+2c\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}\right] \end{aligned}$$

The last expression will be positive if

$$\frac{\left(\frac{2^\beta}{\beta^{2\gamma}}\right)^{\frac{1}{2-\gamma-\beta}}}{\alpha_s^{\frac{\gamma}{2-\beta-\gamma}}} \frac{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2\gamma}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2\gamma}{2-2\gamma-\beta}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+c\theta+\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

$$> \quad \frac{\left(\alpha_1^{\frac{2\beta}{2-\beta-2\gamma}}(1+2c\theta)^{\frac{2\gamma}{2-\beta-2\gamma}}+\alpha_2^{\frac{2\beta}{2-\beta-2\gamma}}(1+2\theta)^{\frac{2\gamma}{2-\beta-2\gamma}}\right)}{\left(\alpha_1^{\frac{2\beta}{2-2\gamma-\beta}}(1+2c\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}+\alpha_2^{\frac{2\beta}{2-2\gamma-\beta}}(1+2\theta)^{\frac{2-\beta}{2-2\gamma-\beta}}\right)^{\frac{\gamma}{2-\beta-\gamma}}}$$

and negative if not. There are parameter values such that the left-hand-side is greater and other parameter values such that the right hand side is greater. For example, for all values of $\alpha_1, \alpha_2, \theta, \beta, \gamma, c$: $\left(\frac{2^\beta}{\beta^{2\gamma}}\right)^{\frac{1}{2-\gamma-\beta}} / \alpha_s^{\frac{\gamma}{2-\beta-\gamma}}$ as a function of $\alpha_s \in \Re^+$ is surjective on positive real numbers and the remaining two fractions are also positive. So the left-hand-side is greater for some values of α_s and the right-hand side greater for other values of α_s.

□

References

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Bhattacharya, D. 2009. "Inferring Optimal Peer Assignment from Experimental Data" *Journal of the American Statistical Association.*

Mas, Alexandre, and Enrico Moretti. 2009. "Peers at Work" *American Economic Review*, 99(1): 112–145.

Appendix Figures

Figure A.1
Distribution of Co-Worker Characteristics for Kikuyu and Luo Suppliers

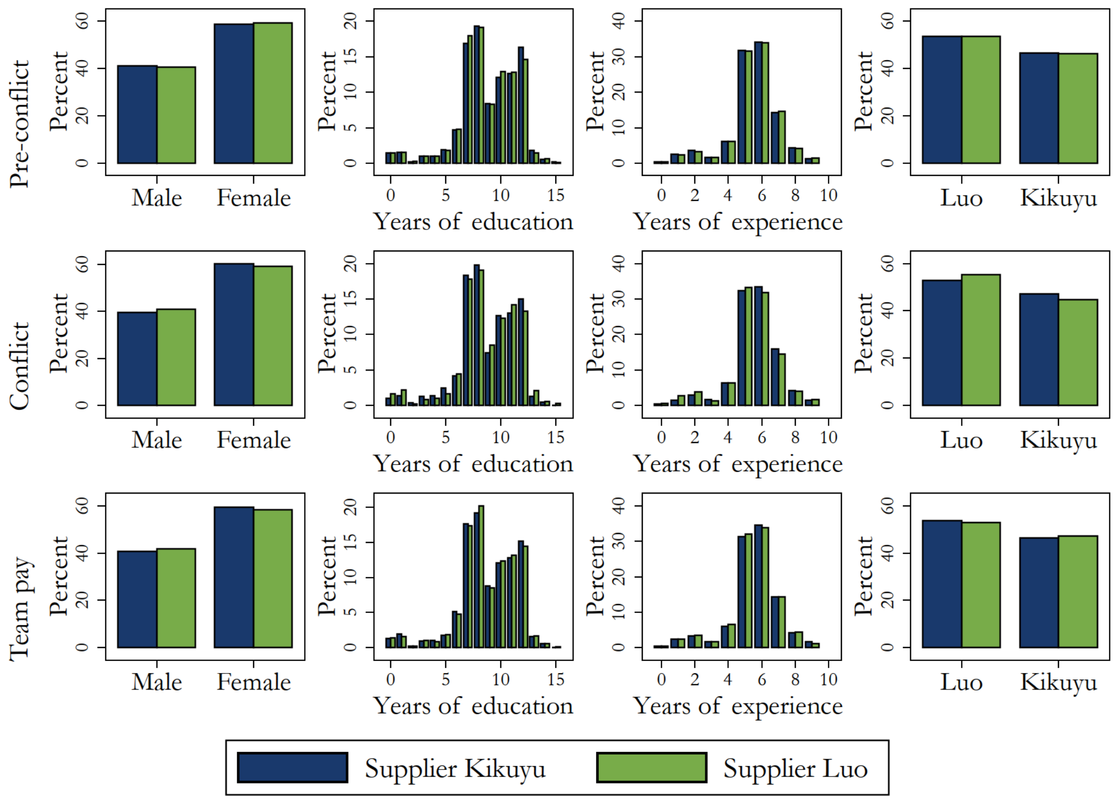


Figure A.2
Distribution of Worker Characteristics in Teams of Different Ethnicity Configurations

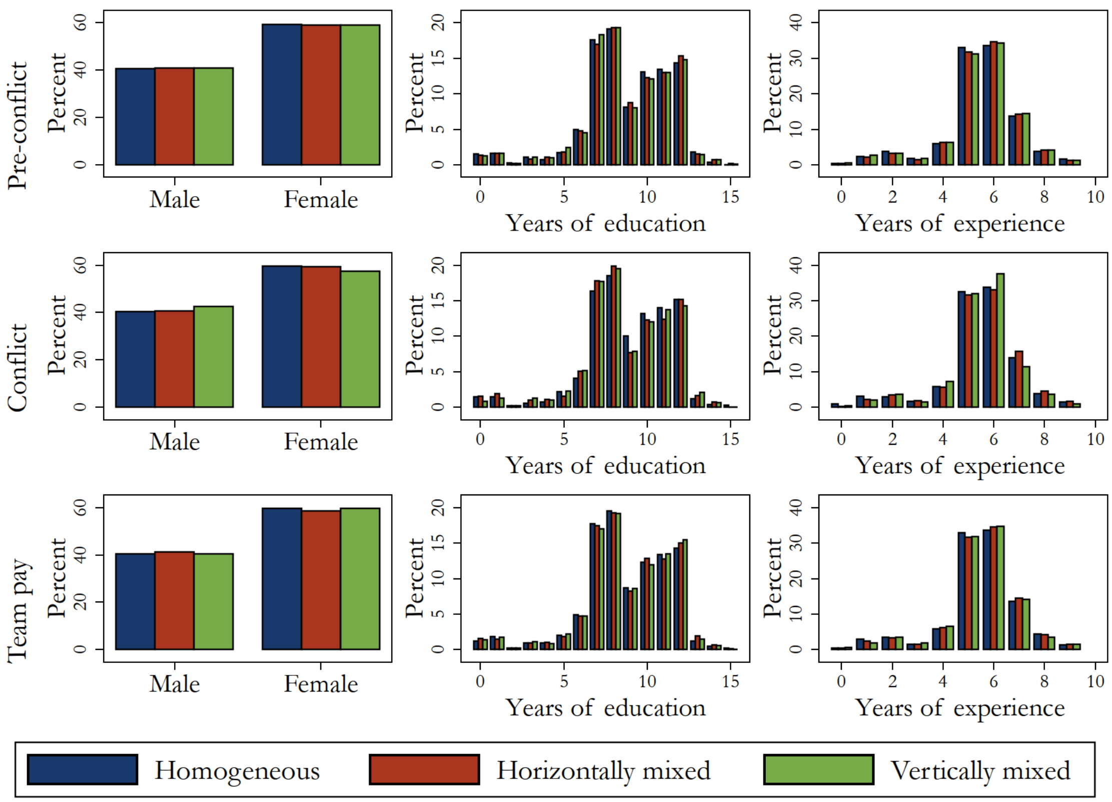
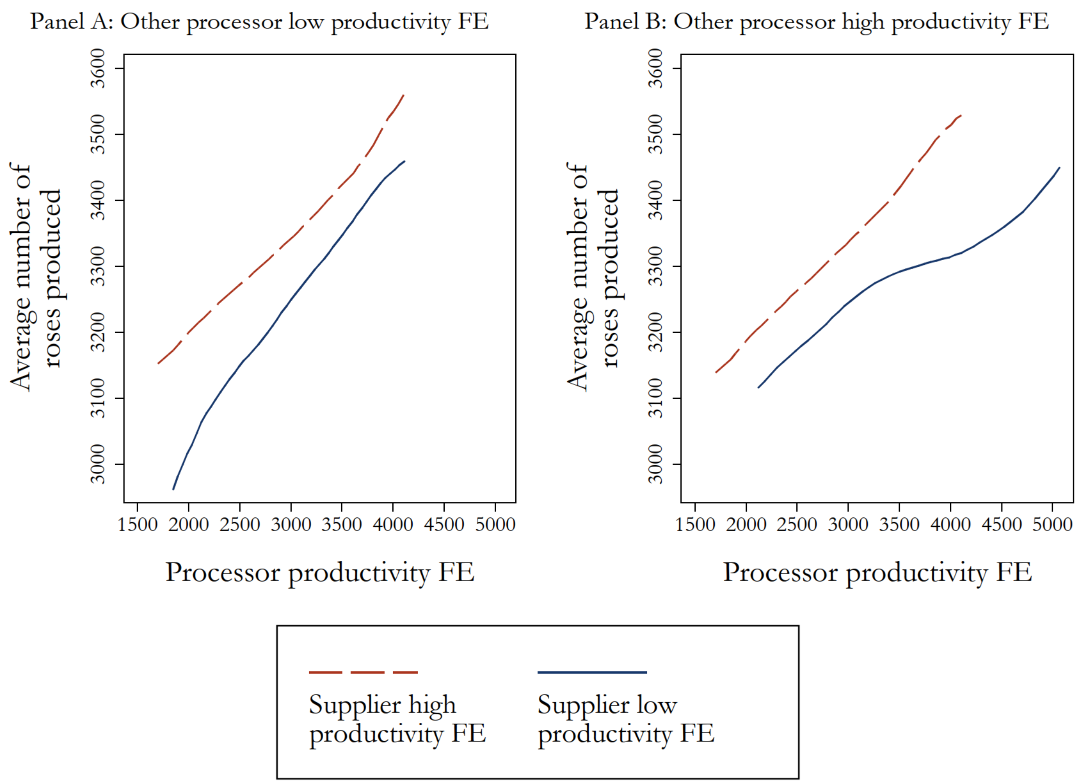
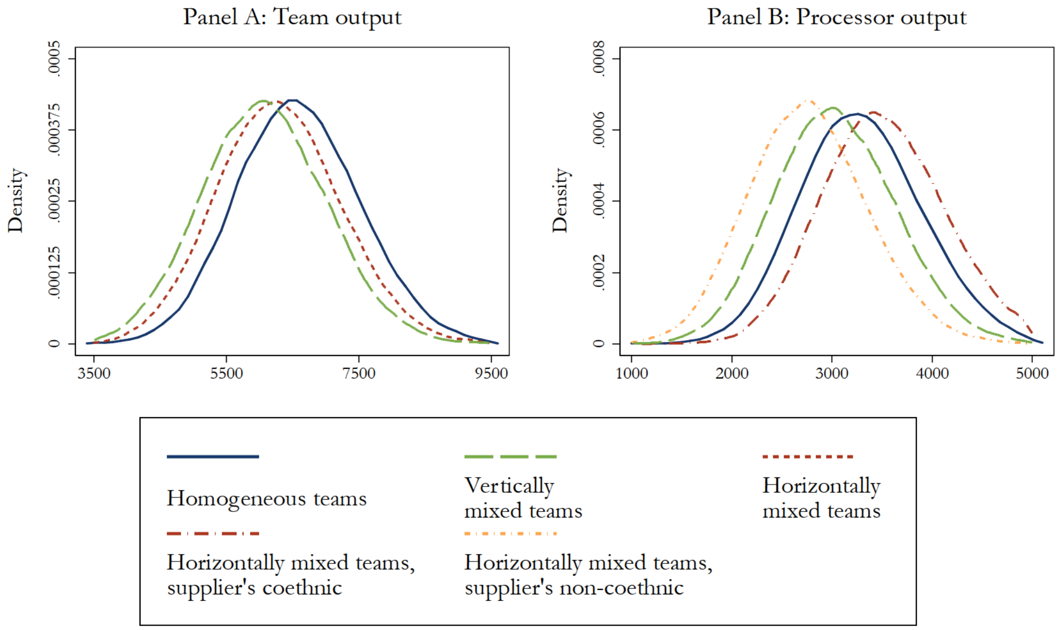


Figure A.3
Investigating the Shape of the Production Function



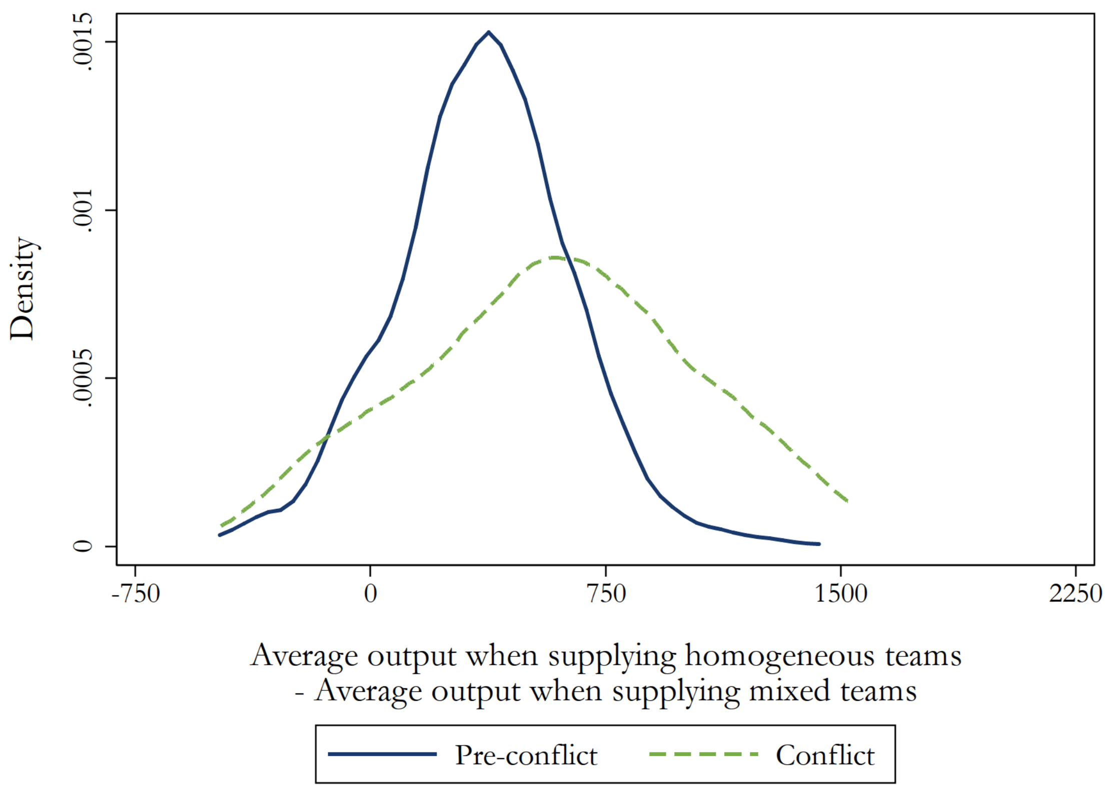
Data from 2007. Outliers (top and bottom percentile) excluded. Local polynomial plots, bandwidth = 350. The processor productivity FE is normalized to have the mean and standard deviation of processor output, and the supplier productivity FE the mean and standard deviation of team output.

Figure A.4
Distribution of Output by Team Ethnicity Configuration



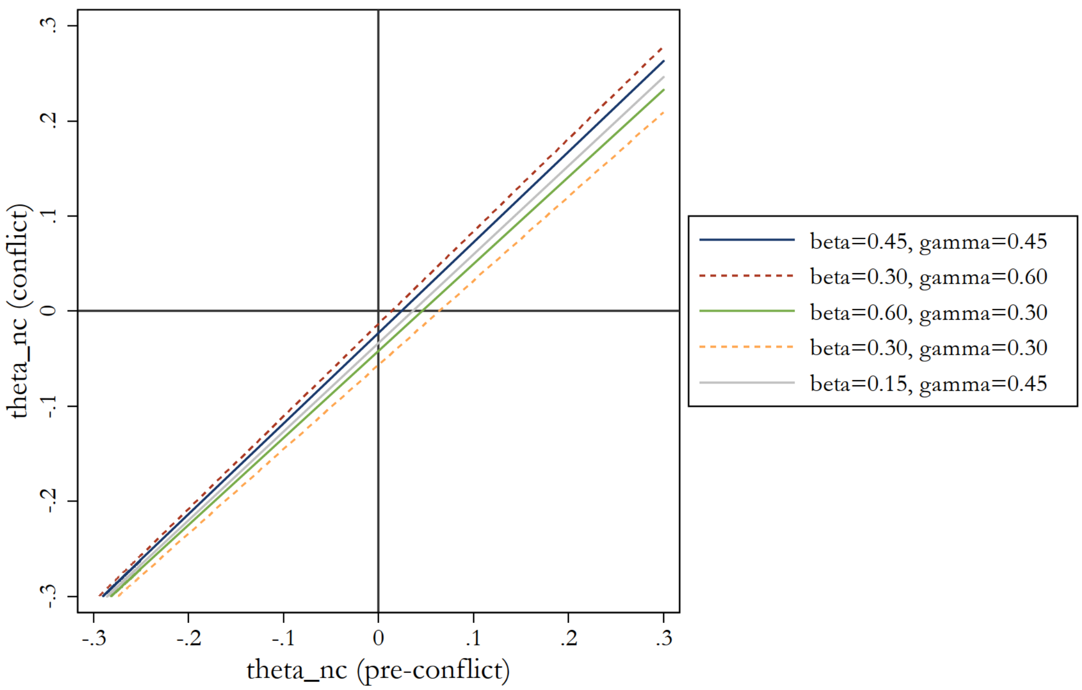
Data from 2007. Local polynomial plots, bandwidth = 100.

Figure A.5
Heterogeneity in Output Gap when Supplying Mixed Teams



Data from 2007 and first 6 weeks of 2008. An observation is the output differential of a given supplier across homogeneous and mixed teams. Outliers (top and bottom percentile) excluded.

Figure A.6
Bounding the Magnitude of the Increase in Taste for Discrimination During Conflict



lambda (pre-conflict) = 0.27, lambda (conflict) = 0.40

Appendix Tables

Table A.1
Supplier Ability Effect by Team Ethnicity Configuration

	Log (Processor output)
	(1)
Supplier high productivity×Horizontally mixed, processor of supplier's ethnicity	−0.002 (0.003)
Supplier high productivity×Horizontally mixed, processor not of supplier's ethnicity	−0.005 (0.003)
Supplier high productivity×Vertically mixed	−0.011*** (0.004)
Constant	8.149*** (0.022)
Horizontally mixed, processor of supplier's ethnicity	0.071*** (0.002)
Horizontally mixed, processor not of supplier's ethnicity	−0.178*** (0.002)
Vertically mixed	−0.079*** (0.003)
N	199026
Person-position FE?	YES
Date FE?	NO
Clustering	Two-way (processor and team)

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The omitted category is processors in homogeneous teams. Data from 2007 is used in this OLS regression. The outcome variables are de-seasonalized, daily output quantities. The Supplier high productivity dummy turns on for those suppliers with above-median average output when working as a supplier (as estimated in the procedure described in section 1 of the appendix).