Essays in Public Economics

Inauguraldissertation zur Erlangung des Doktorgrades
der Wirtschafts- und Sozialwissenschaftlichen Fakultät
der Universität zu Köln

vorgelegt von
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Köln 2021

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Tag der Promotion: 16.02.2022

Acknowledgments

I am very grateful to my advisors, Felix Bierbrauer and Johannes Münster, for introducing me to various interesting facets of economics. I really enjoyed our discussions about economics, research, teaching and politics. I would like to thank you for the freedom you gave me in pursuing my research projects and for providing continuous support. In addition, I would like to thank François Maniquet for hosting be at the UCLouvain during a research stay.

I also benefited greatly from many helpful suggestions from and stimulating discussions with Max Löffler, Emanuel Hansen, Cornelius Schneider, Maj-Britt Sterba, Peter Funk, Thorsten Louis, Jonas Löbbing, Viola Ackfeld, Anna Hartmann and Theresa Markefke.

In particular I would like to thank my coauthor Raphael Flore for countless hours discussing economics, politics and, of course, the fourth chapter of this dissertation.

I am grateful to the Cologne Graduate School for funding my scholarship at the beginning of my dissertation, to the Center for Macroeconomic Research for being a place of many good memories for almost ten years and to the Center for Social and Economic Behavior for financing the research that led to fourth chapter of this dissertation.

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Introduction

This thesis consists of three independent research projects.

Chapter 2, titled “Fair Inheritance Tax”, analyzes fair taxation in an intergenerational framework form a theoretical perspective. The combination of different fairness axioms, most notably Transfer (consumption inequality reducing transfers between otherwise ‘identical’ individuals is socially desirable) and Laissez-faire (if everyone has the same skill level and receives no bequest, taxation is not necessary) imply a concentration on the worst-off in society. Well-being is measured in a particular way: It is given by the wage rate someone would need in a world without taxation and received bequest to be indifferent to the status quo. In terms of taxation the fairness axioms imply a concentration on the highest average taxes payed by low-wage earners, who do not receive a bequest. This research extends Fleurbaey and Maniquet (2006) to an intergenerational context and complements Piketty and Saez (2013); Farhi and Werning (2010, 2013) from a fairness perspective.

Chapter 3, titled “Regulating Multiple Externalities under Uncertainty”, revisits the question of optimal regulations from a theoretical point of view. In 2019 over 3000 economists signed a statement in favor of a uniform carbon tax. On the other hand, economists refer to Weitzman (1974) to defend a carbon tax or a market for CO2-certificates. The contribution of this chapter to the literature is threefold: First, to develop a flexible model to study the regulation of (multiple) externalities under uncertainty. Second, to provide a novel decomposition of Weitzman (1974)’s coefficient of comparative advantage into a quantity, a variance and a covariance effect. Third, to show that this decomposition can be analogously applied to the case of multiple externalities. In particular, under some circumstances, a sector specific regulation is superior to a universal regulation.

Chapter 4, titled “Fair Compensations for Heterogeneous Labor Inputs”, is joint work with Raphael Flore and this study provides novel experimental evidence about normative preferences in situations with heterogeneous labor inputs. For this purpose we conduct an experiment in which impartial spectators choose the fair distribution of output in different scenarios. We argue that these preferences can be explained by an extended version of the ‘equity principle’. We find that spectators reward labor inputs more when they assess them as more tedious, toilsome, or time demanding. Spectators with high levels of education or income also value how intellectually demanding or productive a task is. Additionally, we show that the spectators’ choices are inconsistent with consequentialism.

Chapter 2

Fair Inheritance Tax

2.1 Introduction

In the political debate about inheritance taxation there is one often invoked argument: An inheritance tax is fair because it increases horizontal equity in a society. People from rich or poor families are not responsible for their advantaged or disadvantaged background and therefore it is acceptable to (partly) redistribute resource gains from an inheritance. However, there are at least two points that may conflict with this argument. Although children are not responsible for their initial wealth, parents might have accumulated wealth just for the reason to leave it to their children. This is especially important if income is endogenous: If someone is working hard for her children, it might be counter-productive to tax the wealth she leaves behind because she may reduce her working time (and therefore the revenues from labor taxes decrease). Independent of this mechanical revenue effect, one could also argue that this redistribution is unfair: Consider two families, each with one offspring, where every member of society can earn income at the same wage rate. However, in the first family the parents consume everything themselves and in the second family they leave a bequest for their child. One might argue that it is unfair to tax the family with the altruistic parents more than the family with the selfish parents. This illustrates a tension between the endeavor to decrease inequality on the one hand and respect individual choices on the other hand.

This paper explores the implications of a formalization of the fairness considerations discussed above. The first fairness principle a social decision maker should respect is Transfer: a transfer from someone who is richer in terms of consumption to someone with the same preferences who works the same number of hours and leaves the same amount of bequest, is a social improvement. This principle is very weak in the sense that it compares only individuals with identical preferences where one individual is "unambiguously" better off. This principle implies that inequalities due to different productive abilities or different inheritances are unjust and should be reduced. The second fairness principle is Laissez-faire: In an economy without taxation, where everyone has the same skill level and receives no bequest, the laissez-faire allocations are socially most preferred among the feasible ones. Again, this principle is quite weak because it gives priority to individual choices only in a very symmetrical situation. These two principles are complemented by four additional principles that are standard in the literature on fair social orderings: Order, i.e. social preferences should be complete and transitive; (Weak) Pareto, i.e. strict unanimity of individual preferences should be respected; Independence, i.e. only information about indifference sets should be used; and Separation, i.e. unconcerned individuals should not influence social preferences.

The first part of this paper analyzes social preferences that respect these six fairness principles. As a preliminary result it is shown that one cannot, at the same time, redistribute between individuals with the same preferences and redistribute between dynasties with the same earnings potential. This justifies the use of the Laissez-faire axiom, instead of a stronger axiom. In addition it is shown that the model introduced in this paper nests two models as special cases, the intergenerational model by Fleurbaey (2007) and the labor taxation model by Fleurbaey and Maniquet (2006). The main result of the first part states that an allocation is socially strictly preferred to another allocation if the worst-off individual enjoys a strictly greater well-being. Individual well-being is necessarily given by the answer to the following question: "If you could determine your wage rate and choose your bundle from the laissez-faire budget without receiving a bequest, what wage rate would leave you indifferent to your current situation?".

The second part of the analysis reformulates the allocation centered results of the first part to statements about tax systems. A tax function specifies a tax payment as a function of consumption, bequest left and labor income. Under an auxiliary assumption about the distribution of preferences in society, tax reforms should focus on taxes as a fraction of income ("average taxes") over the smallest budgets. The smallest budgets in this setting are those of individuals with the smallest skill level that receive no bequest. For Germany, minimum wage earners working full time who neither receive nor leave a bequest pay the highest average taxes. Therefore labor or consumption taxes should be reduced for this group while changes in the inheritance tax are expected to be less effective.

The rest of the paper is organized as follows: Section 2.1.1 places the article in the literature, section 2.2 introduces the model, section 2.2.1 states the fairness axioms and section 2.2.2 characterizes fair social orderings. Then the focus shifts to taxation: Section 2.3 introduces taxation, section 2.3.1 translates the results from the previous sections to tax reforms and 2.3.2 illustrates the approach by applying it to Germany while section 2.3.3 compares the results to Piketty and Saez (2013). Finally section 2.4 concludes. The main proofs are gathered in the appendix.

2.1.1 Literature

Three branches of literature are important for this paper. First, the literature on intergenerational social orderings. This literature studies the question how infinitely many individual orderings (or utility functions) can be aggregated into social orderings. Much of the literature focuses on the question how Anonymity, Pareto and additional axioms can be reconciled, see e.g. the impossibility result of Basu and Mitra (2003), the review article of Asheim (2010) and the collection edited by Roemer and Suzumura (2007). Galperti and Strulovici (2017) study the closely related question of the representability of altruistic individual preferences.

Second, the literature on fair social orderings pioneered by Fleurbaey and Maniquet. This literature characterizes transitive and complete social preferences that result from a specific set of fairness axioms. The following axioms are essential ingredients to almost all applications of their approach: The Pareto Principle, Unchanged-Contour Independence (a weaker condition than Arrow-Independence), Separability (unconcerned agents do not influence social evaluation of alternatives) and a restricted form of Pigou-Dalton-Transfer. The exact formulation of the last axiom depends on the context, but the idea is always to identify pairs of individuals where reduced resource inequality is a social improvement. The combination of these axioms leads to a focus on the worst-off in society, where the measure of well-being is not exogenously given but an explicit construction based on normative principles. This paper contributes in two ways to this literature: First, it analyses social preferences in an intergenerational context with endogenous production and generalizes therefore the static model of labor taxation in Fleurbaey and Maniquet (2005, 2006) and the intergenerational endowment economy in Fleurbaey (2006). Somewhat related are the analysis of accidental bequests in Fleurbaey et al. (2017) and the study of risk in an intergenerational setting in Fleurbaey and Zuber (2016). Second, it explicitly studies taxation in an intergenerational context (i.e. labor and inheritance taxes).

Third, the mirrleesian literature on inheritance taxation. This literature analyses optimal labor and inheritance taxation simultaneously, see e.g. Piketty and Saez (2013), Farhi and Werning (2010, 2013) and Kopczuk (2013). In contrast to the fairness literature this literature starts from a utilitarian welfare objective and characterizes optimal tax systems. Piketty and Saez (2013) allow for heterogeneity in skills and preferences and they analyze linear tax systems only. They find that the linear inheritance tax is positive and high if behavioral responses are small, concentration of bequest is high and society favors those with little inheritances. In contrast Farhi and Werning (2010, 2013) study non-linear tax systems with only one type of heterogeneity. In the first paper (without heterogeneous preferences) they show that the optimal inheritance tax is negative but progressive where in the second paper (without production) they clarify the relation between different weighting schemes in the welfare function and (linear) inheritance taxes:

For non-linear taxation and different weighting schemes various tax schedules are possible (e.g. negative and progressive or inverse-U-shaped with positive taxes in the middle). For linear taxes they show that the optimal tax formula can be decomposed into a (positive or negative) Ramsey covariance term plus a (negative) Pigouvian correction term. The literature published before the papers cited above Brunner and Pech (2012a,b); Cremer and Pestieau (2011, 2001); Michel and Pestieau (2004, 2005) studies utilitarian inheritance taxation as well. Because Piketty and Saez (2013) encompass many of these models it will serve a the primary reference point to demonstrate the differences between the utilitarian and the fair approach to taxation.

The present paper deviates from a utilitarian approach for the following reasons: The utilitarian tax rate is determined by inequality aversion pushing tax rates up (at least in some cases) and a Pigouvian correction pushing tax rates down (parents do not internalize the externality posed by the bequest they leave behind). In models with two-dimensional heterogeneity or non-linear tax schedules the relative strength of these two forces is not transparent. More importantly, it is questionable if these two effects are the normatively important ones. In debates about inheritance taxation statements about horizontal equity between individuals (and the right interpretation of this principle) and the freedom of choice of parents are central. Therefore it is more natural to start directly from fairness principles and investigate tax reforms or the optimality of tax systems with respect to these principles. In this sense this research can be seen as complementary to Piketty and Saez (2013) and Farhi and Werning (2010, 2013). While these authors study inheritance taxes given a utilitarian welfare objective this paper starts one step earlier and derives first a welfare objective from basic principles. Another difference lies in the focus on non-linear tax reforms in contrast to optimal (linear) taxes.

While the approach of Saez and Stantcheva (2016) allows to accommodate horizontal equity principles, it is a non-constructive approach: Although one could – in principle – replicate the results of the paper at hand, their approach is of no use in determining the welfare weights in the first place. In addition, the weights depend in general on the allocation considered (and not just on the distribution of preferences and skills), see also Fleurbaey and Maniquet (2018).

2.2 Model

Denote the consumption–bequest–labor bundle of individual dt belonging to dynasty $d \in \mathcal{D} = \{1, ..., D\}$ and generation $t \in \mathcal{T} = \{1, 2, ...\}$ by $x_{dt} = (c_{dt}, b_{dt}, \ell_{dt}) \in \mathcal{X} = \mathbb{R}_+ \times \mathbb{R}_+ \times [0, 1]$. Bequest refers here to the amount the child receives. Note that bequest is bounded below by 0 and labor time is bounded above by 1. Every individual has one child[1], lives for one period and is characterized by a skill level $s_{dt} \in \mathcal{S} = \mathbb{R}_{++}$ and a preference relation R_{dt} defined on $\mathcal{X}$. For future reference denote $s_{inf} := \inf_{d,t} s_{dt}$ and assume in addition $s_{inf} > 0$. $x_{dt}\, R_{dt}\, x'_{dt}$ means that x_{dt} is individually weakly preferred to x'_{dt}; the corresponding strict preference and indifference relations are denoted by P_{dt} and I_{dt}. Throughout it is assumed that preferences satisfy the following standard assumption:

Assumption 1 *Preference Regularity*
Individual preferences are complete, transitive, continuous, convex, increasing in consumption and bequest and decreasing in labor.

The *implicit budget set* with skill level s_{dt} and lump-sum transfer $T \in \mathbb{R}$ is defined by

$$B(T, s_{dt}) = \left\{ x_{dt} \in \mathcal{X} : s_{dt}\ell_{dt} + T \geq c_{dt} + \frac{b_{dt}}{1+r} \right\},$$

where $r \in \mathbb{R}_{++}$ denotes the constant interest rate. E.g. without government intervention the natural budget set for individual dt would be $B(b_{dt-1}, s_{dt})$. Given the implicit budget set, the *set of optimal bundles* for preferences R_{dt} is defined by

$$M(T, s_{dt}, R_{dt}) = \left\{ x_{dt} \in B(T, s_{dt}) : x_{dt} R_{dt} x'_{dt} \text{ for all } x'_{dt} \in B(T, s_{dt}) \right\}.$$

An allocation $x = (x_{dt})_{d\in\mathcal{D}, t\in\mathcal{T}}$ is *feasible* if for all $t \in \mathcal{T}$

$$\sum_{d\in\mathcal{D}, t'\in\mathcal{T}, t'\leq t} (1+r)^{1+t-t'} (s_{dt'}\ell_{dt'} - c_{dt'}) \geq \sum_{d\in\mathcal{D}} b_{dt}$$

where it is implicitly assumed that initial bequests $(b_{d0})_{d\in\mathcal{D}}$ are equal to zero. An allocation x exhibits *bounded present values* if $\sum_{d\in\mathcal{D},t\in\mathcal{T}} (1+r)^{1-t} x_{dt}$ is bounded. An allocation x is *admissible* if $x_{dt} P_{dt} (0, b_{dt}, 0)$ for all d, t. In the following it is assumed that contemplated allocations are admissible and have bounded present values. The task at hand is to characterize Social Ordering Functions (SOF) satisfying the fairness principles introduced in the next section. A SOF $\mathbf{R}(E)$ specifies for every economy $E = (R_{dt}, s_{dt})_{d\in\mathcal{D},t\in\mathcal{T}}$ a binary relation over allocations x. $x\mathbf{R}(E)x'$ means x is socially weakly preferred to x'. Again, the corresponding strict preference and indifference relations are denoted by $\mathbf{P}(E)$ and $\mathbf{I}(E)$.

2.2.1 Fairness Axioms

The first axiom, Order, demands minimal consistency of a SOF. A SOF should order all allocations in a transitive way. This axiom seems innocuous but it should be noted that

[1]Because individuals can only give resources to their single child, these resources are called bequest and inheritance synonymously.

in the literature on intergenerational social orderings the analysis is often restricted to quasi-orderings, i.e. to insist on reflexivity and transitivity only. The problem is, that it is hard to explicitly characterize complete orderings that satisfy Pareto and Anonymity axioms with an infinite population, see Zame (2007). Because the focus of this paper lies on tax reforms it will be sufficient to characterize the asymmetric part of social preferences.

Axiom 1 *Order*
For all E, $\mathbf{R}(E)$ is complete and transitive.

The second axiom, Pareto, states that if everyone strictly prefers one alternative to another, society should do the same. This axiom ensures a minimal sensitivity with respect to individual preferences and forces social preferences to aggregate indices of individual well-being. Because this axiom refers to strict preferences only, this axiom is also known as Weak Pareto. If one insists on Pareto in the present form, one implicitly takes a stand on an issue discussed in the context of the utilitarian approach to bequests: There are preference profiles such that an allocation without bequest might be Pareto dominated by an allocation with identical consumption and labor time but a positive level of bequest. If one sees bequest solely as instrumental to foster heirs, one might want to 'launder' individual preferences of bequest, see e.g. Cremer and Pestieau (2011). Harsanyi (1995) argues more generally that other-regarding preferences should be ignored for social decision making. In this paper individual preferences are respected. It is acknowledged that parents derive a benefit from the act of giving itself, i.e. they assess a situation with low bequest and high governmental transfers for heirs differently from the reverse situation.

Axiom 2 *Pareto*
For all E and x, x', if $x_{dt} P_{dt} x'_{dt}$ for all t and d, then $x\mathbf{P}(E)x'$.

The third axiom, Independence, reflects the idea that, if indifference curves through two allocations stay the same, then the social ranking of these two allocations should also stay the same (independent of whether preferences change elsewhere). Note that this axiom allows for the usage of more information than Arrow Independence and that it is satisfied, for example, by SOFs aggregating money-metric utilities. For an extensive discussion of different independence axioms cf. Fleurbaey et al. (2005). In the following axiom $I(x_{dt}, R_{dt})$ denotes the indifference set of an individual with preferences R_{dt} at the bundle x_{dt}.

Axiom 3 *Independence*
For all E, E' and x, x', if $I(x_{dt}, R_{dt}) = I(x_{dt}, R'_{dt})$ and $I(x'_{dt}, R_{dt}) = I(x'_{dt}, R'_{dt})$ for all t and d, then $x\mathbf{R}(E)x' \Leftrightarrow x\mathbf{R}(E')x'$.

The fourth axiom, Separation, states that an unconcerned individual, i.e. an individual that has the same bundle in two allocations, has no influence on the social ranking of these two allocations: If this individual is removed from the economy altogether, the social ranking does not change. The bequest left of the parent of such an individual could be interpreted as going to a charity. In the following axiom x_{-dt} and E_{-dt} denote the allocation and the economy without individual dt.

Axiom 4 *Separation*
For all E and x, x', if $x_{dt} = x'_{dt}$ for some d, t, then $x\mathbf{R}(E)x' \Rightarrow x_{-dt}\mathbf{R}(E_{-dt})x'_{-dt}$.

The above four fairness axioms are standard in a typical social choice framework studied, for example, in Fleurbaey (2006, 2007); Fleurbaey and Maniquet (2006, 2011b). The following two axioms reflect fairness considerations that are more specific to the intergenerational framework. The fifth axiom, Transfer, reflects the idea that reduced consumption inequality between equals, i.e. individuals with the same preferences, the same labor time and the same bequest left, constitutes a social improvement. Most importantly this axioms implies that inequality due to different skills, different levels of bequests or due to taxation violating horizontal equity, is unfair. Note that this axiom applies to contemporaries as well as to individuals living at different dates. One might argue that this axiom is quite restrictive in two ways. First, it considers only individuals that leave the same bequest and work the same number of hours. However, this should be seen as a strength because the statement is narrowed to a case where it is clear how social preferences should look like. Second, it applies to individuals with identical preferences only. One might be tempted to assess the situation of someone with more consumption, more leisure and more bequest left as unambiguously better then the situation of someone with less in all dimensions, regardless of their preferences. Unfortunately, as Fleurbaey and Trannoy (2003) show, an axiom of this type is incompatible with Pareto. Because the SOF should respect individual preferences in the form of the Pareto principle, one has to insist that Transfer can only be applied to individuals with identical preferences.

Axiom 5 *Transfer*
For all E and x, x', if $R_{dt} = R_{d't'}$, $\ell_{dt} = \ell_{d't'} = \ell'_{dt} = \ell'_{d't}$, $b_{dt} = b_{d't'} = b'_{dt} = b'_{d't'}$ and

$$c'_{dt} - \Delta = c_{dt} > c_{d't'} = c'_{d't'} + \Delta$$

for some d, d', t, t' and $\Delta \in \mathbb{R}_{++}$ and $x_{d''t''} = x'_{d''t''}$ for all $d'' \neq d, d'$ and $t'' \neq t, t'$, then $x\mathbf{R}(E)x'$.

The sixth axiom, Laissez-faire, is again more specific to the intergenerational framework and complements Transfer. It formalizes the idea, that in certain situations the market allocation is fair and should be respected. More specifically the axioms states that the laissez-faire allocation is among the socially most preferred ones, if everyone starts from the same preconditions, that is, everyone has the same skill level and no one receives a lump-sum transfer. In this case everyone chooses from the same budget set and choices from this budget set should be respected. Again, the insistence on this special case is a strength because it limits the axiom to a situation where our intuition about social preferences is strong. Note that this laissez-faire allocation refers to a mostly hypothetical situation: It could be observed only when preferences are such that nobody wants to leave a bequest; otherwise, respecting individual choices is inconsistent with the condition that no one receives a bequest. However, if there is a linear tax τ on bequest left, the child receives $1/(1+r-\tau)$ per unit of bequest the parent leaves. For $\tau \to 1+r$ even altruistic parents would find it optimal to leave zero bequest. Another view on laissez-faire relates to the budgetary externalities bequest produces: The problem with bequest is not that individuals decide to buy the special 'commodity' bequest – especially if everyone chooses from the same budget set – but that someone else receives the expenditures on bequest. From this point of view, the hypothetical situation where everyone chooses bequest left from the same budget set and at the same time no one receives a bequest, is socially optimal. Transfer and Laissez-faire are depicted in figure 2.2.

Axiom 6 *Laissez-faire*
For all E such that $s_{dt} = s$ for some fixed s and all d, t, all feasible x, x', if $x_{dt} \in M(0, s, R_{dt})$ for all d, t, then $x\mathbf{R}(E)x'$.

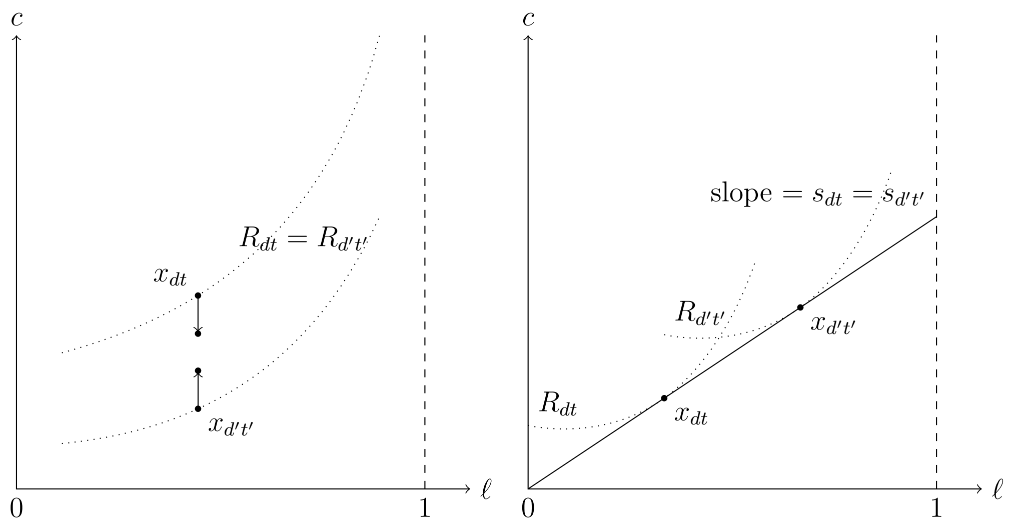


Figure 2.1: Transfer and Laissez-faire (bequest orthogonal to slide)

Laissez-faire can be viewed from a different angle as well. It states conditions under which the intradynastrial distribution of resources should be respected. Laissez-faire allows a priori for the possibility that individuals in one dynasty are more altruistic than in another dynasty. One might be tempted to strengthen Laissez-faire to an axiom that recommends redistribution from rich to poor dynasties. A natural measure of wealth in the present context would be the implicit lump-sum transfer a dynasty receives, measured in consumption goods of period $t = 1$. The implicit lump-sum transfer in a given period corresponds to the difference between consumption and labor income. In addition, choices of individuals belonging to the dynasties considered should be optimal in the respective budget sets. Otherwise this axiom would be incompatible with Pareto. Similar to Transfer, which describes circumstances under which redistribution between individuals with identical preferences constitutes a social improvement, one can formulate Transfer among Dynasties, which describes circumstances under which redistribution between dynasties with identical earnings potential constitutes a social improvement.

Axiom 7 *Transfer among Dynasties*
For all E and x, x', if $(s_{d1}, s_{d2}, ...) = (s_{d'1}, s_{d'2}, ...)$,

$$\sum_{t\in\mathcal{T}} \frac{c'_{dt} - s_{dt}\ell'_{dt}}{(1+r)^{t-1}} - \Delta = \sum_{t\in\mathcal{T}} \frac{c_{dt} - s_{dt}\ell_{dt}}{(1+r)^{t-1}} > \sum_{t\in\mathcal{T}} \frac{c_{d't} - s_{d't}\ell_{d't}}{(1+r)^{t-1}} = \sum_{t\in\mathcal{T}} \frac{c'_{d't} - s_{d't}\ell'_{d't}}{(1+r)^{t-1}} + \Delta,$$

and, for all t, $x^{(\prime)}_{d^{(\prime)}t} \in M\left(c^{(\prime)}_{d^{(\prime)}t} + b^{(\prime)}_{d^{(\prime)}t}/(1+r) - s^{(\prime)}_{d^{(\prime)}t}\ell^{(\prime)}_{d^{(\prime)}t}, s^{(\prime)}_{d^{(\prime)}t}, R^{(\prime)}_{d^{(\prime)}t}\right)$ for some d, d' and $\Delta \in \mathbb{R}_{++}$ and $x_{d''t} = x'_{d''t}$ for all $t, d'' \neq d, d'$, then $x\mathbf{R}(E)x'$.

Unfortunately, as is shown in the following section, Transfer and Transfer among Dynasties are incompatible with each other as long as one insists on Order and Pareto.

2.2.2 Social Orderings

In this section the shape of social ordering functions satisfying the above axioms is studied. The first result states that one cannot have Transfer, Transfer among Dynasties, Order and Pareto at the same time. Intuitively, for a well-off individual in a poor dynasty and a worse-off individual in a rich dynasty, the two transfer axioms recommends redistribution in opposite directions, which allows for the construction of cycles in social preferences. For illustration consider an economy with two dynasties d and d' with preferences $R_{d1} = R_{d'1}$ and skills $s_{dt} = s_{d't}$ for all t. Let x be an allocation where individuals $d'1$ and $d1$ are identical except that consumption is higher for $d2$. Let x' be an allocation, that is weakly better in terms of Transfer. Let x'' be an allocation that has consumption levels of everyone slightly reduced but redistributes overall from richer dynasty d to poorer dynasty d' (if choices are optimal Transfer among Dynasties can be applied). If x is chosen to Pareto-dominate x'', this construction leads to an incomparability with Order. Note that even without Pareto the two transfer principles imply social indifference for a wide range of constellations.

Proposition 1 *Suppose individual preferences satisfy Preference Regularity. Then there is no SOF satisfying Order, Pareto, Transfer and Transfer among Dynasties.*

Proof: The following argument assumes $r = 1$ but can be easily generalized to arbitrary $r > 0$. Consider the economy

$$E = ((R_1, 1), (R_1, 1); \quad (R_{d2}, 1), (R_{d'2}, 1); \quad (R_{d3}, 1), (R_{d'3}, 1); \quad ...)$$

and the allocations

$$\begin{aligned} x &= ((5,1,1),(2,1,1); \quad (2,1,1),(8,1,1); \quad (2,1,1),(8,1,1); \quad ...), \\ x' &= ((4,1,1),(3,1,1); \quad (2,1,1),(8,1,1); \quad (2,1,1),(8,1,1); \quad ...), \\ x'' &= \left(\left(\frac{47}{12},0,\frac{1}{6}\right),\left(\frac{23}{12},0,\frac{2}{3}\right); \quad \left(\frac{23}{12},0,\frac{1}{6}\right),\left(\frac{83}{12},0,\frac{2}{3}\right); \quad \left(\frac{23}{12},0,\frac{1}{6}\right),\left(\frac{83}{12},0,\frac{2}{3}\right); \quad ...\right). \end{aligned}$$

Suppose preferences are such that

$$\begin{aligned} &(5,1,1)R_1\left(\frac{47}{12},0,\frac{1}{6}\right) \in M\left(\frac{15}{4},1,R_1\right), \quad (2,1,1)R_1\left(\frac{23}{12},0,\frac{2}{3}\right) \in M\left(\frac{5}{4},1,R_1\right), \\ &(2,1,1)R_{d2}\left(\frac{23}{12},0,\frac{1}{6}\right) \in M\left(\frac{7}{4},1,R_{d2}\right), \quad (8,1,1)R_{d'2}\left(\frac{83}{12},0,\frac{2}{3}\right) \in M\left(\frac{25}{4},1,R_{d'2}\right), \\ &(2,1,1)R_{d3}\left(\frac{23}{12},0,\frac{1}{6}\right) \in M\left(\frac{7}{4},1,R_{d3}\right), \quad (8,1,1)R_{d'3}\left(\frac{83}{12},0,\frac{2}{3}\right) \in M\left(\frac{25}{4},1,R_{d'3}\right), ... \end{aligned}$$

By Transfer,

$$x'\mathbf{R}(E)x,$$

by Transfer among Dynasties,

$$x''\mathbf{R}(E)x',$$

by Pareto

$$x\mathbf{P}(E)x'',$$

by Order

$$x\mathbf{P}(E)x,$$

a contradiction. $\square$

The conflict between these two axioms is closely related to the conflict between compensation and responsibility, e.g. discussed in Fleurbaey and Maniquet (2011a): On the one hand, individuals should be compensated for undeserved disadvantages, and on the other hand, individuals should be held accountable for their preferences. Although one can debate to what degree people are responsible for their preferences, it seems reasonable that a social planer should not satisfy expensive tastes in general. E.g. in the model at hand one cannot justifiable demand compensatory payments if one has a low labor income due to a high valuation of leisure. For the remainder of the paper this fundamental conflict between dynasty- and individual-centered redistribution is resolved in favor of the latter one. The reason for this is twofold: The Transfer axiom is already quite restrictive because it refers only to individuals that leave the same bequest, work the same number of hours and have identical preferences. It is not obvious how to weaken Transfer sufficiently to make it compatible with Transfer among Dynasties and keep the individualistic focus of the axiom. Furthermore, Transfer among Dynasties looks at the dynastic wealth only and places little weight on the distribution of bequest. Individuals matter only insofar as individual choices are required to be optimal in the respective budget set. In the following the joint implications of axioms 1–6 are explored.

The model introduced above is similar to two models discussed in the literature. Fleurbaey (2007) characterizes fair SOFs in an overlapping generations model without labor and without bequests. The main result in Fleurbaey (2007) states that one should focus on the worst-off where well-being is measured by the answer to the following question: "If you would receive a lump-sum transfer and you could choose your bundle from the laissez-faire budget, what transfer would leave you indifferent to your current situation?" Fleurbaey and Maniquet (2006) and Fleurbaey (2006) on the other hand characterize fair SOFs in a static model. Again one should focus on the worst-off where well-being is now measured by the question: "If you could determine your wage rate and you could choose your bundle from the laissez-faire budget, what wage rate would leave you indifferent to your current situation?" The following theorem derives an analogous result for the intergenerational model with bequest:

Theorem 1 *Suppose individual preferences satisfy Preference Regularity. If a SOF $\mathbf{R}(E)$ satisfies Order, Pareto, Independence, Separation, Transfer and Laissez-faire, then for all x, x',*

$$\inf_{d \in \mathcal{D}, t \in \mathcal{T}} s(x_{dt}, R_{dt}) > \inf_{d \in \mathcal{D}, t \in \mathcal{T}} s(x'_{dt}, R_{dt}) \quad \Rightarrow \quad x\mathbf{P}(E)x',$$

where $s(x_{dt}, R_{dt}) = \min\{s \in \mathcal{S} : x'_{dt} R_{dt} x_{dt}$ for some $x'_{dt} \in B(0, s)\}$.

Proof: See appendix.

Analogously to the papers cited above, the theorem states that one should focus on the worst-off where well-being is measured by the answer to the following question:

"If you could determine your wage rate and you could choose your bundle from the laissez-faire budget and you would not receive a bequest, what wage rate would leave you indifferent to your current situation?" So $s(\cdot)$ belongs to the class of skill-equivalent well-being indices, in contrast to the lump-sum equivalent indices discussed extensively in Fleurbaey and Maniquet (2018). The restriction to admissible allocations guarantees that this well-being index is well-defined, the construction is depicted in figure 2.2.

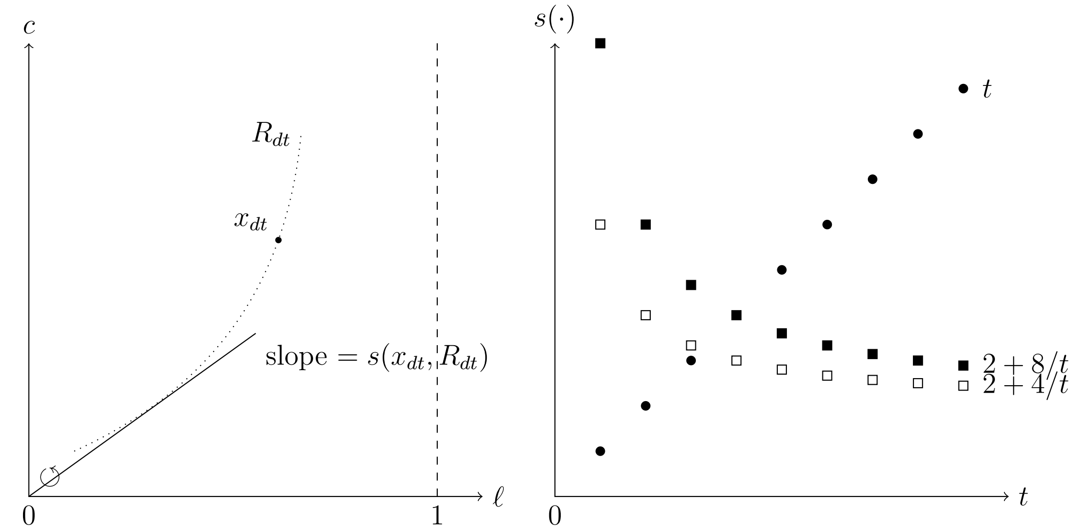


Figure 2.2: No bequest-skill-equivalent index (bequest orthogonal to slide) and three dynasties example (sequences of squares not comparable but both preferable to sequence of circles)

A SOF satisfying the axioms in the propositions is called *fair*. A clarification concerning the complete characterization of social preferences is in order. First, the asymmetric part of a fair SOF has to focus on the infimum of all well-being indices, that is, the worst-off individual is decisive for social evaluations. The necessity for the infimum instead of the minimum criterion arises because one cannot a priori exclude the possibility of falling well-being for the worst-off in the far future. However, if one thinks that the worst-off will reach a higher level of satisfaction in the future, the minimum is well defined and can be found in the near future. Note that weak social preferences $\mathbf{R}(E)$ *cannot* evaluate situations according to $\inf s(\cdot)$ because the infimum criterion does not satisfy Pareto. This situation is illustrated in figure 2.2: The two square-sequences cannot be compared because $\lim_{t\to\infty} 2 + 8/t = \lim_{t\to\infty} 2 + 4/t = 2$ despite the fact that $2 + 8/t > 2 + 4/t$ for all $t \in \mathbb{N}_+$. So, how does the weak part of social preferences look like? Unfortunately the complete characterization of fair SOFs relies so far on free ultrafilters defined on the set of dates and therefore the construction is not explicit, see e.g. Fleurbaey and Michel (2003) and Fleurbaey (2007). If one weakens Order and insists on transitivity only, one can formulate an overtaking criterion of the following kind: Prefer an allocation iff there exists some date t' such that for all $t'' \geq t'$ the worst-off in the population up to date

t'' is better off. Because the focus lies on the evaluation of tax regimes, the result of Theorem 1 suffices for the purpose of this paper. The following corollary shows that the model presented in this paper nests the models from Fleurbaey and Maniquet (2006) and Fleurbaey (2007) as special cases. For Fleurbaey (2007) bequest has to be adjusted as follows: Individuals have preferences over the resources they leave behind and the resources get destroyed after interest payments but before the children inherit them (so bequests received do not appear in the children's budget constraint and an allocation is feasible if $\sum_{d,t}(1+r)^{1-t}(s_{dt} - c_{dt} - b_{dt}/(1+r)) \geq 0$).

Corollary 1 *(i) Suppose individual preferences satisfy Preference Regularity, but are constant in labor (and everyone works full-time). If a SOF* $\mathbf{R}(E)$ *satisfies Order, Pareto, Independence, Transfer and Laissez-faire (with the modification above), then for all* x, x'*,*

$$\inf_{d\in\mathcal{D},t\in\mathcal{T}} \tilde{s}(x_{dt}, R_{dt}) > \inf_{d\in\mathcal{D},t\in\mathcal{T}} \tilde{s}(x'_{dt}, R_{dt}) \quad \Rightarrow \quad x\mathbf{P}(E)x',$$

where $\tilde{s}(x_{dt}, R_{dt}) = \min\{T \in \mathbb{R} : x'_{dt}R_{dt}x_{dt}$ *for some* $x'_{dt} \in B(T, 0)\}$*.*
(ii) Suppose individual preferences satisfy Preference Regularity, but are constant in bequest (and no one leaves a bequest). If a SOF $\mathbf{R}(E)$ *satisfies Order, Pareto, Independence, Separation, Transfer and Laissez-faire, then for all* x, x'*,*

$$\inf_{d\in\mathcal{D},t\in\mathcal{T}} \tilde{\tilde{s}}(x_{dt}, R_{dt}) > \inf_{d\in\mathcal{D},t\in\mathcal{T}} \tilde{\tilde{s}}(x'_{dt}, R_{dt}) \quad \Rightarrow \quad x\mathbf{P}(E)x',$$

where $\tilde{\tilde{s}}(x_{dt}, R_{dt}) = \min\{s \in \mathbb{R} : x'_{dt}R_{dt}x_{dt}$ *for some* $x'_{dt} \in B(0, s)\}$*.*

Proof: (i) In Fleurbaey (2007) bequest left is interpreted as consumption when old, Laissez-Faire is called Equality and Transfer refers to situations where consumption and bequest are strictly bigger. Therefore Theorem 1 in Fleurbaey (2007) can be applied.
(ii) The model in Fleurbaey and Maniquet (2006) and the present model differ in the studied population sizes: The population in the first paper is finite where in this paper the population is (countable) infinite. The proof of Theorem 1 in Fleurbaey and Maniquet (2006) has to be adjusted analogously to the proof of Theorem 1 in this paper (see appendix). □

Where the previous corollary shows that the model simplifies if the dimensionality of the consumption space decreases, the next corollary generalizes the result of Theorem 1 to higher dimensional consumption spaces. In the baseline model there is only one consumption good and one "bequest good". However, in reality one might want to differentiate between transmitted houses, luxury goods, money, etc. In Germany, for example, owner-occupied housing is exempt from the inheritance tax. Formally, let $(c_{dt}, b_{dt}) \in \mathbb{R}^n_+ \times \mathbb{R}^n_+$ for some $n \in \mathbb{N}_+$ and denote the price vector by $p \in \mathbb{R}^n_{++}$. Consequently, in the definition of the implicit budget set c_{dt} and b_{dt} have to be replaced by $p \cdot c_{dt}$ and $p \cdot b_{dt}$, where $\cdot$ denotes the inner vector product.

Corollary 2 *If consumption and bequest are n-dimensional vectors, Theorem 1 continues to hold (with the adjusted definition of the implicit budget set).*

Proof: The proof of Theorem 1 goes through unaltered, see also Fleurbaey (2006) □

The next section translates these results to statements about tax systems. Note, that from a fairness perspective, a high skill or inheritance does not justify high consumption *per se*, but likewise the results do not necessarily imply high taxes on labor income or inheritances: Consider a dynasty with strong preferences for leaving bequest and a decreasing skill sequence. From an incentive perspective, high labor/inheritance taxes discourage working and leaving bequests. Theorem 1 rather suggests a Rawlsian difference principle, that is, inequalities are justified if the socially disadvantaged benefit from them.

2.3 Taxation

The analysis up to this point has focused on comparing different allocations. In the following the implications for tax reforms are explored. The aim is to construct simple statistics that can be used to compare different tax systems. Note that a tax system in this context specifies labor income and inheritance tax rates simultaneously. A complication of the intergenerational model is the possibility of time-inconsistent policies. E.g. the government might want to tax someone higher when her parents die, if the reason for the low tax burden was the well-being of her parents. In the following analysis it is assumed that the well-being of the dead matter for the above axioms. That is, from a fairness perspective, the "betrayal" of the dead is evaluated the same way as if they were still alive. For the generations $..., -2, -1, 0$ it is assumed that their preferences are irrelevant. The task at hand is to translate the allocation-centered result of the first theorem to a statement about tax payments. However, in the present model, tax systems are potentially very complicated objects, as in the new dynamic public finance literature (see e.g. Golosov et al. (2007)): The government could implement date-specific taxes, behave time-inconsistent or condition taxes an agent has to pay on other's behavior. While one can in principle compare arbitrarily complicated tax systems by comparing the induced allocations, this approach does not allow to make statements just by looking at the tax function. Therefore the following analysis is restricted to tax functions $\tau : \mathbb{R}^3_+ \rightarrow \mathbb{R}$ such that the tax payment of individual dt, $\tau(c_{dt}, b_{dt}, s_{dt}\ell_{dt})$, depends on consumption, bequest left and labor income only. Note that these tax functions are still much more general than the budget-balancing affine-linear tax functions studied in Piketty and Saez (2013). The implicit budget set with taxation is then given by

$$B(b_{dt-1}, s_{dt}, \tau) = \left\{ x_{dt} \in \mathcal{X} : s_{dt}\ell_{dt} + b_{dt-1} \geq c_{dt} + \frac{b_{dt}}{1+r} + \tau(c_{dt}, b_{dt}, s_{dt}\ell_{dt}) \right\}.$$

Note that taxes do not depend on bequest received b_{dt-1} or solely on skill s_{dt} or labor time ℓ_{dt} (but on the product of skill and labor time $y_{dt} := s_{dt}\ell_{dt}$). With a slight abuse of notation we denote consumption–bequest–income-bundles by $x_{dt} = (c_{dt}, b_{dt}, y_{dt})$ as well. The implicit budget set then reads

$$B(b_{dt-1}, s_{dt}, \tau) = \left\{ x_{dt} \in \mathbb{R}_+^2 \times [0, s_{dt}] : y_{dt} + b_{dt-1} \geq c_{dt} + \frac{b_{dt}}{1+r} + \tau(c_{dt}, b_{dt}, y_{dt}) \right\}.$$

Analogously one can define preferences over consumption–bequest–income-bundles. Denote the set of bundles such that the budget constraint holds with equality by $\partial B(b_{dt-1}, s_{dt}, \tau)$. In the next section tax reforms are analyzed.

2.3.1 Tax Reforms

In this section the focus shifts from the pairwise comparison of allocations to the pairwise comparison of tax functions. For simplicity the analysis is restricted to tax functions where it is not possible to cut taxes without affecting behavior (in a sense there are no free-lunch tax reforms). Formally, a tax function τ is *minimal* if there is no other tax function $\tau' \leq \tau$ such that everyone chooses the same bundle. That is, minimal tax functions coincide with the lower envelope of individual preferences (where non-minimal tax systems might coincide only at bundles that are actually chosen). The necessity to distinguish between minimal and non-minimal tax functions comes in part from the fact, that the population is not modeled as a continuum: 'Well-behaved' tax functions for a continuum population are automatically minimal. An example is depicted in figure 2.3.

Proposition 1 implies a concentration on the worst-off individuals, measured by a skill-equivalent well-being index without bequest. The assessment of tax systems is potentially very complicated because the implicit unrestricted domain assumption with respect to preferences and skill levels allows a priori for atypical constellations of the following kind: There could be labor income brackets in the bottom of the income distribution with only high-skilled individuals. If the government is not able to observe skill, it is hard to judge whether a tax reduction at some low income level is an improvement or not. The following assumption, which is along the lines of Low-Skill Diversity in Fleurbaey and Maniquet (2006), excludes those cases. More specifically it states that for any low labor income that an agent might choose there exists a low-skilled agent with no or the same level of

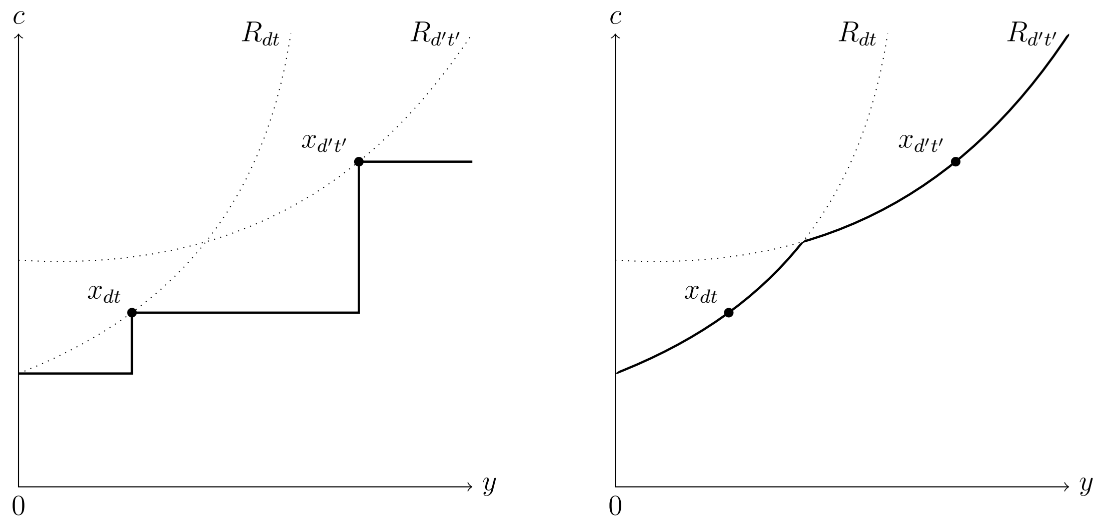


Figure 2.3: Non-minimal and minimal taxes (bequest orthogonal to slide)

bequest received, who has locally similar preferences. In the following $uc((c, b, y), s_{dt}, R_{dt})$ denotes the closed upper contour set of agent dt for the bundle (c, b, y).

Assumption 2 *Preference Diversity*
For every individual dt and bundle (c, b, y) with $y \leq s_{inf}$, there is an individual $d't'$ that receives the same level of bequest (and one that receives no bequest) with $s_{d't'} = s_{inf}$ and $uc((c, b, y), s_{d't'}, R_{d't'}) \subseteq uc((c, b, y), s_{dt}, R_{dt})$.

This assumption implies in particular that if an individual chooses a bundle with a low labor income, there is a low-skilled individual without received bequest that chooses the same bundle, if they choose from the same budget set. Given two minimal tax systems, which tax system is more desirable? To answer this question, one has to identify the worst-off according to Theorem 1. Given Preference Diversity, the next result shows that the worst-off agents are those that pay the highest fraction of their income as taxes among those low-income earners, that do not receive an inheritance.

Theorem 2 *Suppose individual preferences satisfy Preference Regularity and Preference Diversity. If a SOF $\mathbf{R}(E)$ satisfies Order, Pareto, Independence, Separation, Transfer and Laissez-faire, then for all minimal tax schedules τ, τ' and corresponding allocations x, x',*

$$\max_{(c,b,y) \in \partial B(0, s_{inf}, \tau)} \frac{\tau(c, b, y)}{y} < \max_{(c,b,y) \in \partial B(0, s_{inf}, \tau')} \frac{\tau'(c, b, y)}{y} \quad \Rightarrow \quad x \mathbf{P}(E) x'.$$

Proof: See appendix.

This result might seem counterintuitive: Should a labor-inheritance tax reform not focus on tax payments of productive rich heirs, if one agrees with the fairness principles proposed before? This line of reasoning is misleading in this model, because the focus of (strict) social preferences lay on low-skilled without inheritance only. A fair SOF would indeed endorse redistribution from rich to poor, but the focus lies on improving the poor's situation and not on redistributing away from rich individuals. Note that the only information about the population needed is the smallest skill level s_{inf}, which could be interpreted as the minimum wage or minimal social security transfers. As an example, suppose that there is a linear value added consumption tax $\tau_c \geq 0$. The metric to evaluate the tax system is then given by

$$M(\tau,\tau_c) := \max_{b,y} \frac{\tau_c\left(y - \frac{b}{1+r}\right) + \tau(b,y)}{(1+\tau_c)\,y} \quad \text{s.t.} \quad s_{inf} \geq y \geq \frac{b}{1+r} + \tau(b,y).$$

If $M(\tau,\tau_c) < M(\tau',\tau_c')$, then the tax system (τ,τ_c) is socially preferred over (τ',τ_c'). Intuitively, $M(\tau,\tau_c)$ is the highest fraction (max operator) of their labor income (expression after the max operator) that income-poor individuals (first inequality), who do not receive a bequest (second inequality), have to pay. In practice, one can calculate this metric easily in a three-step-procedure: First, calculate the average tax burden for arbitrary bundles (c,b,y). Second, restrict attention to bundles that are budget feasible for low-skilled individuals that do not receive a bequest themselves. Third, determine the highest average tax burden in this group. This procedure is qualitatively depicted in figure 2.4: Each dotted ellipse represents bundles where the average tax burden is constant (called Isotaxburden in the graphic). The dashed lines correspond to the restriction of budget feasibility.[2] The point M depicts the highest average tax burden among the budget feasible bundles.

2.3.2 Application to the German Tax System

To illustrate the simplicity of the approach, the following section analyzes the German tax system. The German tax code in 2020 (pre-Corona) is roughly described by the following three components:

[2] The intersection of the curved dashed line and the vertical solid line is given by the value of b solving $0 = b/(1+r) + \tau(b,0)$. Whether the curved dashed line is convex or concave, depends on the tax system. In case the tax function is differentiable, we have

$$\frac{db}{dy} = \frac{1-\tau_y}{\frac{1}{1+r}+\tau_b} \qquad \text{and} \qquad \frac{d^2b}{dy^2} = -\frac{\tau_{yy}\left(\frac{1}{1+r}+\tau_b\right)^2 + \tau_{bb}\,(1-\tau_y)^2 + 2\tau_{by}\left(\frac{1}{1+r}+\tau_b\right)(1-\tau_y)}{\left(\frac{1}{1+r}+\tau_b\right)^3}.$$

E.g. for an additively separable tax system ($\tau_{by} = 0$) that is progressive in labor income and bequest left ($\tau_{yy}, \tau_{bb} \geq 0$), the curved dashed line is concave as in figure 2.4.

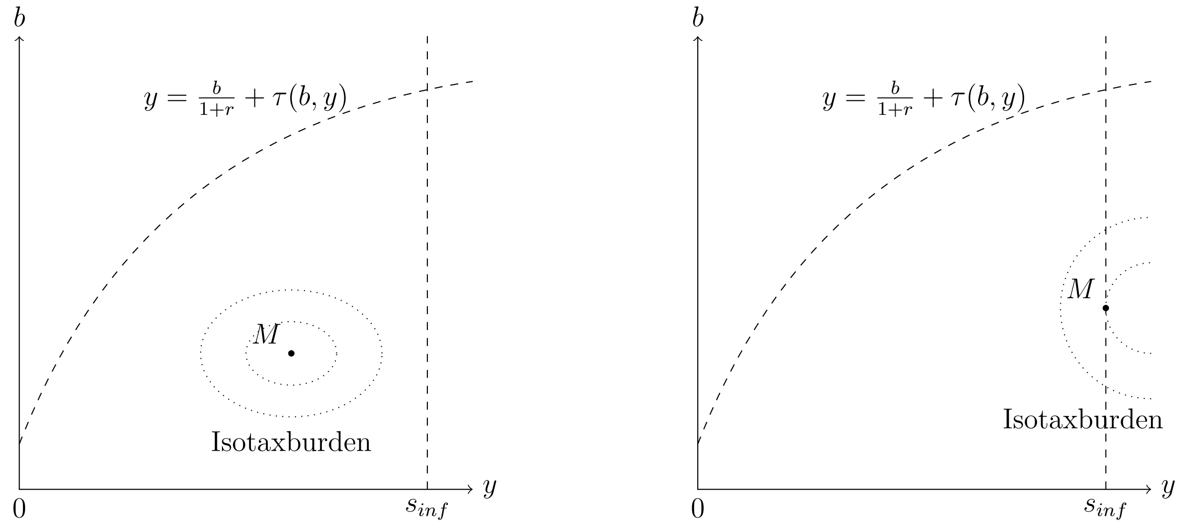


Figure 2.4: Metric to evaluate a tax system: interior and corner solution. For the general case of a nonlinear consumption tax the increasing dashed line is implicitly characterized by the equation $y = \frac{b}{1+r} + \tau(0, b, y)$.

1. The regular VAT rate in Germany is 19%, with a reduced rate of 7% for necessities. Because the interest lies solely on the budget sets of 'poor' people, this is averaged to $\tau_c = 13\%$ (ignoring rent, energy taxes, etc.).

2. The inheritance tax has a free allowance of $\underline{b} = 400000$ EUR for children and marginal taxes increase stepwise from 7% on wealth ≤ 75000 EUR to 30% on wealth ≥ 26000000 EUR. Again, because the interest lies solely on the budget sets of 'poor' people, this is averaged to $\tau_b = 11\%$ above the free allowance (ignoring free allowances for personal belongings and different taxation of housing and company assets).

3. The labor income tax payment is a quadratic function of yearly income: Up to 9408 EUR labor taxes are zero. Beyond that up to 57051 EUR marginal taxes increase linearly (with a change in the slope at 14532 EUR). After that marginal taxes are constant (with a change from 42% to 45% at 270500 EUR). For simplicity the German tax and transfer system will be approximated by a constant-rate-of-progressivity tax function $y - \lambda y^p$. In line with previous evidence (Heathcote et al. (2017); Kindermann et al. (2020)) the progressivity parameter is set to $p = 0.2$ and $\lambda = 13$ to match the break even income of ≈ 230000 EUR (i.e. the income where the sum of taxes, transfers and social security payments is equal to zero; again it is abstracted from many details concerning the tax, transfer and social security system).

Taken together, the German tax function can be approximated by

$$\tau(c, b, y; \tau_c, \tau_b, \underline{b}, \lambda, p) = \tau_c c + \tau_b \max\{b - \underline{b}, 0\} + y - \lambda y^p,$$
$$\tau(c, b, y; 0.13, 0.11, 400000, 13, 0.8) = 0.13c + 0.11 \max\{b - 400000, 0\} + y - 13y^{0.8}.$$

Finally, the interest rate is set to $r = 0.8$ as in Piketty and Saez (2013) and $s_{inf} = 800000$ to approximate the lifetime earnings of a minimum wage worker:

$$
\begin{aligned}
M(\tau_c, \tau_b, \underline{b}, \lambda, p) &= \max_{b,y} \frac{\tau_c \left(y - \frac{b}{1+r} \right) + \tau_b \max\{b - \underline{b}, 0\} + y - \lambda y^p}{(1+\tau_c)\, y} \\
\text{s.t.} \quad s_{inf} \geq y, &\quad \frac{-\frac{b}{1+r} - \tau_b \max\{b - \underline{b}, 0\} + \lambda y^p}{1+\tau_c} \geq 0, \\
M(0.13, 0.11, 400000, 13, 0.8) &= \max_{b,y} 1 + \frac{-0.13\frac{b}{1+r} + 0.11 \max\{b - 400000, 0\} - 13y^{0.8}}{1.13y} \\
\text{s.t.} \quad s_{inf} \geq y, &\quad \frac{-\frac{b}{1+r} - 0.11 \max\{b - 400000, 0\} + 13y^{0.8}}{1.13} \geq 0 \\
&= 0.241,
\end{aligned}
$$

where the maximum is attained by $(c, b, y) = (607207, 0, 800000)$. This corresponds graphically to the intersection of the dashed vertical line and the solid horizontal line in Figure 2.4. The highest average tax rate of 24.1% is payed by minimum wage earners working full-time and spending everything on consumption goods. Therefore tax reforms should lower consumption and labor taxes, while (small) changes in the inheritance tax do not affect welfare. However, if inheritance taxes change drastically, say to $\tau_b = 20\%$, the highest average taxes of 29.6% are payed by minimum wage earners working full-time that leave all their net incomes to their children (this implies, perhaps unrealistically, zero consumption for the parents). This corresponds to the intersection of the dashed vertical line and the dashed increasing line in Figure 2.4. In that case, reducing consumption taxes is ineffective and one should reduce inheritance taxes and labor taxes.

From this example one can see that the policy recommendations of this approach depend crucially on the shape of the current tax schedule: If the tax schedule is such that individuals who pay the highest average taxes do not consume certain commodities (bequest or consumption), then lowering taxes on these commodities is ineffective. However, one should be cautious to conclude from this observation that one can increase taxes on these commodities by an arbitrary amount. If taxes become very high individuals consuming much of this commodity are considered the worst-off and one should lower average taxes for this new group.

2.3.3 Comparison to Piketty and Saez (2013)

Piketty and Saez (2013) show in a very similar model that a small increase in the linear inheritance tax τ_b (accompanied by a budget-balancing decrease of the linear labor tax τ_y) increases utilitarian welfare iff

$$\frac{1 - e_b\tau_b/(1-\tau_b)}{1 - e_y\tau_y/(1-\tau_y)}\bar{y} - \bar{b}^{received}(1+\bar{e}_b) - \frac{\bar{b}^{left}}{(1+r)(1-\tau_b)} \geq 0, \tag{2.1}$$

where e_b and e_y are the elasticities of aggregate bequest and aggregate labor income w.r.t. $1-\tau_b$ and $1-\tau_y$; furthermore $\bar{y}, \bar{b}^{received}, \bar{b}^{left}$ and $\bar{e}_b$ denote the welfare weighted normalized averages of labor income, bequest received, bequest left and e_b, respectively.[3] The three terms in the formula correspond to the welfare effects of the reduced labor tax, the welfare effects on bequest received and the welfare effects on bequest left. A small increase in τ_b is therefore desirable if welfare weighted normalized bequests are small, if behavioral responses w.r.t. bequests are small and if behavioral responses w.r.t. labor are high. The analysis in Piketty and Saez (2013) differs from the one in this paper in various dimensions: The authors consider only small inheritance tax reforms of a linear tax system that are budget neutral. In contrast the formula in Theorem (2) holds for big reforms that might not be budget balanced and the formula applies to nonlinear tax systems. Nevertheless, some aspects of the results can be compared. The first term in equation (2.1) has no counterpart in Theorem (2) because it corresponds to the mechanical increase in the labor tax due to the restriction to budget balanced tax reforms. The last two terms in equation (2.1) imply that a small increase in the inheritance tax increases utilitarian welfare if society puts little weight on bequest receivers and bequest leavers. On the other hand, Theorem (2) states that a tax reform increases welfare if the maximal average tax burden for low-skilled no-bequest receivers decreases. Whether or not inheritance taxes for this subgroup should be lowered depends on the subpopulation that is decisive: If individuals paying the highest average taxes leave bequest, then inheritance taxes should be lowered. However if those individuals do not leave bequest they would not profit from an inheritance tax reduction and welfare would not increase necessarily. In that case a reduced consumption or labor tax would be better from a welfare perspective (this was illustrated by the German tax system in the previous subsection).

Farhi and Werning (2010, 2013) analyze inheritance taxation in a slightly different model: Heterogeneity is unidimensional but the inheritance tax is nonlinear. They show that 'anything goes' with an appropriate specification of utilitarian welfare weights, but for the baseline specification optimal inheritance taxes are negative and progressive.

[3] Bequest refers here to bequest before taxes and interest payments. This is a notational difference only, for the formal definitions see section 2 in Piketty and Saez (2013).

Overall, utilitarian policy recommendations depend on the exact welfare weights which might limit the practical use of simple looking formulas such as (2.1) or the analogue formulas in Farhi and Werning (2010, 2013). In contrast, Theorem (2) requires information about s_{inf} and a segment of the tax schedule only.

2.4 Conclusion

This paper shows that one has to focus tax reforms on the highest average tax burden of the income-poor who do not receive a bequest, if one accepts the fairness principles proposed in this paper. In particular two notions of horizontal equity were proposed: Reduced consumption inequality between equals is socially desirable and if everyone chooses from the same budget set, the laissez-faire allocation can be respected. These two principles together imply social preferences that concentrate on the worst-off in society, where well-being is measured in comparison to a hypothetical laissez-faire world. Under an auxiliary assumption about the distribution of preferences, the worst-off are found among those agents with the smallest budget sets.

2.A Appendix

Assume throughout the appendix that individual preferences satisfy Preference Regularity. The proof of Theorem 1 relies on the following lemmas:

Lemma 1 *If a SOF* $\mathbf{R}(E)$ *satisfies Order, Pareto, Independence and Transfer, then for all* x, x'*, if*

$$\begin{aligned} x'_{dt} P x_{dt} P x_{d't'} P x'_{d't'} & \quad \text{for some pair } dt, d't' \text{ with } R_{dt} = R_{d't'} = R \text{ and} \\ x_{d''t''} P_{d''t''} x'_{d''t''} & \quad \text{for all } d''t'' \neq dt, d't', \end{aligned}$$

we have $x\mathbf{P}(E)x'$*.*

Proof: Note that from the point of view of transfer, bequest is more similar to leisure than to consumption. Let x, x' be allocations satisfying the conditions in the lemma. By Independence, social preferences remain unchanged if R changes at bundles elsewhere than $I(x_{dt}, R) \cup I(x'_{dt}, R) \cup I(x_{d't'}, R) \cup I(x'_{d't'}, R)$. Now one can construct intermediate indifference surfaces and bundles, analogously to lemma 1 in Fleurbaey and Maniquet (2006): The intermediate indifference surfaces are given by the lower boundary of the convex hull of

$$\begin{aligned} I(x'_{dt}, R) \cup \{(c, 0, 0)\} \quad & \text{where} \quad (c, 0, 0) \in I(x_{dt}, R) \quad \text{and} \\ I(x_{d't'}, R) \cup \{(c, 0, 0)\} \quad & \text{where} \quad (c, 0, 0) \in I(x'_{d't'}, R) \end{aligned}$$

By looking at intermediate bundles located on and near the intermediate indifference curves, that are comparable by Transfer, one concludes by Pareto and Order, that $x\mathbf{P}(E)x'$. Details of the precise construction of these intermediate bundles can be found in the appendix of Fleurbaey and Maniquet (2006). While Fleurbaey (2006) applies this construction to multiple consumption goods, this paper applies it to multiple leisure goods. $\square$

Lemma 2 *If a SOF* $\mathbf{R}(E)$ *satisfies Order, Pareto, Independence, Separation, Transfer and Laissez-faire, then for all* x, x'*, if*

$$\begin{aligned} s(x'_{dt}, R_{dt}) > s(x_{dt}, R_{dt}) > s(x_{d't'}, R_{d't'}) > s(x'_{d't'}, R_{d't'}) & \quad \text{for some pair } dt, d't' \text{ and} \\ x_{d''t''} = x'_{d''t''} & \quad \text{for all } d''t'' \neq dt, d't', \end{aligned}$$

we have $x\mathbf{P}(E)x'$*.*

Proof: Denote the initial economy by E and the economy consisting of dynasties d and d' only (satisfying the conditions stated in the lemma) by E'. To simplify notation denote $(x_{dt})_{t\in\mathcal{T}}$ by x_d. Let s be such that $s(x_{dt}, R_{dt}) > s > s(x_{d't'}, R_{d't'})$. Consider now the economy E'' consisting again of dynasties d and d' where everyone has the same skill level s and preferences are such that leaving no bequest is individually optimal under laissez-faire. Denote the laissez-faire allocation in this economy by $(x_d^{LF}, x_{d'}^{LF})$ and let $(\tilde{x}_d, \tilde{x}_{d'})$ be another feasible but inefficient allocation such that for all $k \in \mathcal{T}$,

$$s(x_{dt}, R_{dt}) > s(\tilde{x}_{dk}, R_{dk}) > s > s(\tilde{x}_{d'k}, R_{d'k}) > s(x_{d't'}, R_{d't'}).$$

For concreteness let $(\tilde{x}_d, \tilde{x}_{d'})$ be such that $\tilde{b}_{dt} = \tilde{b}_{d't} = 0$ for all t and

$$0 < \sum_{t \in \mathcal{T}} (1+r)^{1-t} \left(s\tilde{\ell}_{dt} + s\tilde{\ell}_{d't} - \tilde{c}_{dt} - \tilde{c}_{d't} \right) =: \varepsilon.$$

$(\tilde{x}_d, \tilde{x}_{d'})$ is Pareto-dominated by $(\tilde{\tilde{x}}_d, \tilde{\tilde{x}}_{d'})$, where for all t,

$$\begin{aligned} \tilde{\tilde{b}}_{dt} &= \tilde{b}_{dt}, \quad \tilde{\tilde{b}}_{d't} = \tilde{b}_{d't}, \quad \tilde{\tilde{\ell}}_{dt} = \tilde{\ell}_{dt}, \quad \tilde{\tilde{\ell}}_{d't} = \tilde{\ell}_{d't}, \\ \tilde{\tilde{c}}_{dt} &= \tilde{c}_{dt} + \frac{\varepsilon r}{4(1+r)}, \quad \tilde{\tilde{c}}_{d't} = \tilde{c}_{d't} + \frac{\varepsilon r}{4(1+r)}. \end{aligned}$$

By construction, $(\tilde{\tilde{x}}_d, \tilde{\tilde{x}}_{d'})$ is feasible. Finally, let $E''' = E' \cup E''$.
By Laissez-faire,

$$(x_d^{LF}, x_{d'}^{LF}) \mathbf{R}(E'') (\tilde{\tilde{x}}_d, \tilde{\tilde{x}}_{d'})$$

by Pareto,

$$(\tilde{\tilde{x}}_d, \tilde{\tilde{x}}_{d'}) \mathbf{P}(E'') (\tilde{x}_d, \tilde{x}_{d'})$$

by Order,

$$(x_d^{LF}, x_{d'}^{LF}) \mathbf{P}(E'') (\tilde{x}_d, \tilde{x}_{d'})$$

by Separation,

$$(x_d^{LF}, x_{d'}^{LF}, x_d, x_{d'}) \mathbf{P}(E''') (\tilde{x}_d, \tilde{x}_{d'}, x_d, x_{d'}).$$

Remember that for all $k \in \mathcal{T}$,

$$s(x'_{dt}, R_{dt}) > s(x_{dt}, R_{dt}) > s(\tilde{x}_{dk}, R_{dk}) > s(x_{dt}^{LF}, R_{dt}) = s$$

and

$$s = s(x_{d't'}^{LF}, R_{d't'}) > s(\tilde{x}_{d'k}, R_{d'k}) > s(x_{d't'}, R_{d't'}) > s(x'_{d't'}, R_{d't'}).$$

One cannot immediately conclude via lemma 1 that the allocation $(x_d, x_{d'}^{LF}, \tilde{x}_d, x'_{d'})$ is strictly preferred to $(x'_d, x_{d'}^{LF}, x_{dt}^{LF}, x'_{d'})$ because many individuals receive the same bundles in both contemplated allocations (and are hence indifferent between both allocations). The same is true for the allocations $(x_d, x_{d'}, \tilde{x}_d, \tilde{x}_{d'})$ and $(x_d, x_{d'}^{LF}, \tilde{x}_d, x'_{d'})$, respectively.

Therefore one needs to construct intermediate, strictly preferred bundles to apply lemma 1. Note that one can partition the set of individuals into three groups of agents: (i) Individuals dt and $d't'$, (ii) individuals $dk, k \neq t$ and $d'k', k' \neq t'$ and (iii) all other individuals.

For group (iii) no construction of intermediate bundles is necessary because Separation can be applied.

For group (i) consider the bundles $x_{dt}^a, x_{dt}^b, x_{dt}^c$ and $x_{d't'}^a, x_{d't'}^b, x_{d't'}^c$ satisfying

$$x_{dt}^a P_{dt} x'_{dt} P_{dt} x_{dt} P_{dt} x_{dt}^b P_{dt} \tilde{x}_{dt} P_{dt} x_{dt}^c P_{dt} x_{dt}^{LF}$$

and

$$x_{d't'}^a P_{d't'} x_{d't'}^{LF} P_{d't'} \tilde{x}_{d't'} P_{d't'} x_{d't'} P_{d't'} x_{d't'}^b P_{d't'} x_{d't'}^c P_{d't'} x'_{d't'}.$$

For group (ii) consider the bundles $x_{dk}^a, x_{dk}^b, x_{dk}^c$ for all $k \neq t$ and $x_{d'k'}^a, x_{d'k'}^b, x_{d'k'}^c$ for all $k' \neq t'$ satisfying

$$x_{dk}^a P_{dk} x'_{dk} = x_{dk} P_{dk} x_{dk}^b P_{dk} \tilde{x}_{dk} P_{dk} x_{dk}^c P_{dk} x_{dk}^{LF}$$

and

$$x_{d'k'}^a P_{d'k'} x_{d'k'}^{LF} P_{d'k'} \tilde{x}_{d'k'} P_{d'k'} x_{d'k'}^b P_{d'k'} x_{d'k'}^c P_{d'k'} x'_{d'k'} = x_{d'k'}.$$

By Lemma 1,

$$(x_d^c, x_{d'}^a, x_d^b, x_{d'}^b) \mathbf{P}(E''')(x_d^{LF}, x_{d'}^{LF}, x_d^a, x_{d'}^c)$$

and

$$(\tilde{x}_d, \tilde{x}_{d'}, x_d, x_{d'}) \mathbf{P}(E''')(x_d^c, x_{d'}^a, x_d^b, x_{d'}^b),$$

by Order,

$$(\tilde{x}_d, \tilde{x}_{d'}, x_d, x_{d'}) \mathbf{P}(E''')(x_d^{LF}, x_{d'}^{LF}, x_d^a, x_{d'}^c)$$

and

$$(x_d^{LF}, x_{d'}^{LF}, x_d, x_{d'})\mathbf{P}(E''')(x_d^{LF}, x_{d'}^{LF}, x_d^a, x_{d'}^c),$$

by Separation,

$$(x_d, x_{d'})\mathbf{P}(E')(x_d^a, x_{d'}^c),$$

by Pareto,

$$(x_d, x_{d'})\mathbf{P}(E')(x'_d, x'_{d'}),$$

by Separation,

$$x\mathbf{P}(E)x',$$

which concludes the proof. □

Lemma 3 *Let R be a preference relation defined over a convex set $X \subset \mathbb{R}^n$ and denote the open lower contour set at $x \in X$ by $L(x, R)$. Then for all pairs $x, x' \in X$ such that xPx' there exist countably many $x^1, x^2, ...$ such that $xP...Px^2Px^1Px'$.*

Proof: R is continuous iff for all pairs $x, x' \in X$ such that xPx' there exist open balls $B_x, B_{x'}$ around x, x' such that for all $y \in B_x, y' \in B_{x'}$ we have yPy'. For $x^1 \in B_x \cap L(x, R)$ (the intersection is non-empty by monotonicity) this implies in particular xPx^1Px'. Applying this step again to the pair x, x^1 yields xPx^2Px^1Px'. Proceeding iteratively yields the result. □

Proof of Theorem 1: Let x, x' be allocations satisfying the conditions in the theorem. Let $\tilde{x}, \tilde{x}'$ be allocations such that

$$\begin{cases} s(x_{dt}, R_{dt}) > s(\tilde{x}_{dt}, R_{dt}) \quad \text{and} \quad s(\tilde{x}'_{dt}, R_{dt}) > s(x'_{dt}, R_{dt}) & \text{for all } dt, \\ s(\tilde{x}'_{dt}, R_{dt}) > s(\tilde{x}_{dt}, R_{dt}) > s(\tilde{x}_{d't'}, R_{d't'}) > s(\tilde{x}'_{d't'}, R_{d't'}) & \text{for some } d't' \text{ and all } dt \neq d't'. \end{cases}$$

With Lemma 3, consider the sequence of allocations $\{x^n\}_{n \in \mathbb{N}_+}$ given by, for $dt \neq d't'$,

$$x_{dt}^n = \begin{cases} \tilde{x}'_{dt}, & \text{for } n \leq D(t-1) + d, \\ \tilde{x}_{dt}, & \text{for } n > D(t-1) + d, \end{cases}$$

and

$$\begin{cases} \tilde{x}_{d't'} P_{d't'} x^{n+1}_{d't'} P_{d't'} x^n_{d't'} P_{d't'} \tilde{x}'_{d't'} & \text{for } n \neq D(t'-1)+d', \\ x^{n+1}_{d't'} = x^n_{d't'} & \text{for } n = D(t'-1)+d'. \end{cases}$$

By construction, for all dt such that $Dt+d \neq Dt'+d'$,

$$s(x^{D(t-1)+d}_{dt}, R_{dt}) > s(x^{D(t-1)+d+1}_{dt}, R_{dt}) > s(x^{D(t-1)+d+1}_{d't'}, R_{d't'}) > s(x^{D(t-1)+d}_{d't'}, R_{d't'})$$

and for all dt and all $d''t'' \neq d't', dt$,

$$x^{D(t-1)+d+1}_{d''t''} = x^{D(t-1)+d}_{d''t''},$$

by Lemma 2, for all $n \neq D(t'-1)+d'$,

$$x^{n+1}\mathbf{P}(E)x^n$$

and

$$x^{D(t'-1)+d'+1} = x^{D(t'-1)+d'},$$

by Pareto

$$x^1\mathbf{P}(E)x'$$

and, for all $n \in \mathbb{N}_+$,

$$x\mathbf{P}(E)x^n,$$

by Order,

$$x\mathbf{P}(E)x',$$

which concludes the proof. □

Proof of Theorem 2: The proof shows that the inequality in tax rates translates to an inequality in well-being indices $s(\cdot)$:

By the definition of $s(\cdot)$,

$$\inf_{d,t} s(x_{dt}, R_{dt}) = \inf_{d,t} \min \left\{ s : (c,b,y) R_{dt} x_{dt} \text{ for some } (c,b,y) \in B(0,s) \right\},$$

by the definition of $B(0,s)$,

$$= \inf_{d,t} \min \left\{ \frac{s_{dt}}{y} \left(c + \frac{b}{1+r} \right) : (c,b,y) R_{dt} x_{dt} \right\},$$

by the definition of $uc(\cdot)$,

$$= \inf_{d,t} \min_{(c,b,y) \in uc(x_{dt}, s_{dt}, R_{dt})} \frac{s_{dt}}{y} \left(c + \frac{b}{1+r} \right),$$

by the minimality of τ and Preference Diversity $(*)$,

$$= \min_{(c,b,y) \in \partial B(0, s_{inf}, \tau)} \frac{s_{inf}}{y} \left(c + \frac{b}{1+r} \right),$$

by the definition of $B(0, s_{inf}, \tau)$,

$$= s_{inf} \min_{(c,b,y) \in \partial B(0, s_{inf}, \tau)} \left(1 - \frac{\tau(c,b,y)}{y} \right),$$

where step $(*)$ is true for the following reasons, see also Fleurbaey and Maniquet (2006): First, the minimality of τ implies that the tax function coincides with the lower envelope of the indifference surfaces, i.e. one can refer to budget sets instead of upper contour set under the minimum operator. Second, Preference Diversity and the fact that individuals with smaller budget sets are worse off, imply that the relevant indifference curves are those of the low skilled that do not receive a bequest. The last equality implies

$$\begin{aligned} & \inf_{d,t} s(x_{dt}, R_{dt}) > \inf_{d,t} s(x'_{dt}, R_{dt}) \\ \Leftrightarrow \quad & \max_{(c,b,y) \in \partial B(0, s_{inf}, \tau)} \frac{\tau(c,b,y)}{y} < \max_{(c,b,y) \in \partial B(0, s_{inf}, \tau')} \frac{\tau'(c,b,y)}{y} \end{aligned}$$

and by Theorem 1 the result follows. $\square$

Chapter 3

Regulating Multiple Externalities under Uncertainty

3.1 Introduction

In 2019 over 3000 economists, including many nobel laureates, signed a statement in favor of a uniform carbon tax. The statement states that “a carbon tax will send a powerful price signal that harnesses the invisible hand of the marketplace” and “A [...] carbon tax will replace the need for various carbon regulations that are less efficient”.[1] The logic behind this statement is pervasive in all of economics: After correcting for externalities (by assigning property rights or implementing a pigouvian tax) no further regulation is necessary and markets allocate resources efficiently. Although not explicitly mentioned in the statement, this argument relates to an implication of the famous Diamond and Mirrlees (1971a,b) production efficiency result: If final goods can be taxed freely, there is no need for the government to interfere in the production process by taxing intermediate inputs. The logic of this result is very simple: Every agent should face the same prices such that the reduction in emissions is achieved wherever the costs of reducing emissions are the lowest.

Almost half a century earlier Weitzman (1974) posed the question, whether a price or a quantity regulation of a single externality is superior in the presence of uncertainty. In the Weitzman (1974) model a central authority equalizes expected private marginal benefits to expected private marginal costs by either fixing a quantity directly of fixing marginal costs by setting a price. However, the central authority does not know the vertical positions of marginal benefits or costs a priori (so there is ‘intercept uncertainty’). The central result in Weitzman (1974) says that a price regulation is superior to a quantity regulation if and only if the marginal costs of reduced emissions change quickly com-

[1] See `www.wsj.com/articles/economists-statement-on-carbon-dividends-11547682910` for the original statement and `www.econstatement.org` for a list of all signatories.

pared to marginal benefits. This formulation as well as the subsequent literature on the coefficient of comparative advantage is restrictive in multiple ways: While Stavins (1996) pointed out the importance of taking correlations between private costs and benefits seriously, he still restricts himself to intercept uncertainty. More fundamentally, Laffont (1977) points out the dual structure of the Weitzman (1974)) model: Instead of comparing fixed quantities with fixed marginal costs (a producer price regulation), one could also fix marginal benefits (a consumer price regulation). He shows that with intercept uncertainty only, the quantity regulation is always dominated by either a consumer or a producer price regulation. However, the restriction to the specific welfare objective (equalize marginal benefits and marginal costs) in conjunction with the regulation of behavior derived from a specific private objective (equalize marginal benefits or marginal costs to a price), obfuscates the underlying logic behind the coefficient of comparative advantage: Under what circumstances is it socially beneficial to allow private agents to respond to new information?[2]

The purpose of this paper is threefold: To build a simple but generic model study the regulation of (multiple) externalities under uncertainty; to uncover the underlying logic behind the coefficient of comparative advantage of prices over quantities introduced in Weitzman (1974) and to study quadratic regulations[3]; to extend the single good analysis to two goods.

The paper proceeds as follows: Section 3.1.1 discusses additional literature. Section 3.2 introduces the generic framework that will be used throughout the analysis. Section 3.3 analyses the single good case: Optimal price, quantity and quadratic regulations are characterized to derive the coefficient of comparative advantage of a price over a quantity regulation; subsequently, the cost-benefit-analysis from Weitzman (1974) is studied as a special case. Section 3.4 analyses, analogously to the previous section, the multiple goods case: Optimal price, quantity, total quantity and quadratic regulations are characterized to derive various coefficients of comparative advantage; subsequently, atmospheric externalities are studied as a special case. Finally, section 3.5 discusses matters of implementation and microfoundation and concludes. All proofs are gathered in the appendix.

[2]Depending on the origin of private behavior – consumption benefits, production costs, market clearing – the coefficient of comparative advantage recommends very different policies.

[3]While there are multiple papers (e.g. Weitzman (1978) or Roberts and Spence (1976)) studying the optimal mix of a price and a quantity regulation, these papers are still restricted to the cost-benefit-analysis of the original Weitzman (1974) paper. In this paper optimal quadratic regulations, which nest pure price and pure quantity regulations as special cases, are studied. Roberts and Spence (1976), in contrast, study linear regulations with a kink. As for the coefficient of comparative advantage, the generic model allows for a more transparent derivation of the optimal quadratic regulation.

3.1.1 Additional Literature

The literature on externality regulation under uncertainty is part of a larger literature on the general theory of externality regulation. Cropper and Oates (1992) and Bovenberg and Goulder (2002) summarize this literature, see also Mehling et al. (2018) for a policy oriented discussion of different regulations and Berger and Marinacci (2020) for a discussion about the role of uncertainty in modeling externality regulation.[4]

This paper contributes mainly to the literature studying the regulation of externalities under uncertainty. There are many papers following Weitzman (1974) that analyze the comparative advantage of a price over a quantity regulation. The most important ones for the paper at hand are Laffont (1977, 1978), who points out the dual structure of the Weitzman model. That is, instead of a producer price regulation one could also implement a consumer price regulation. The model introduced in the paper at hand is agnostic towards the behavior that should be regulated. Stavins (1996) stresses the importance of correlations between private costs and social benefits and he shows that the simple intuition for the case of uncorrelated costs and benefits can be misleading (a point that can be analyzed more generally with the framework proposed in this paper). Stavins (2020) provides a recent comparison between price and quantity regulations. Kaplow and Shavell (2002); Kaplow (2010) argue in favor of price over quantity regulations on the basis that prices can be more easily adjusted.Caillaud and Demange (2017) discuss under what circumstances one might want to tax some subset of firms and set up an emission market for another subset. Fabra and Montero (2020) study the differences between uniform and differential regulations and derive coefficients of comparative advantages for various cases. Most of the results in Fabra and Montero (2020) are nested by this paper.

In addition there is a literature studying (non-)linear regulations. In particular, Roberts and Spence (1976) study linear regulations with a kink and show that these regulations perform better than pure price and quantity regulations. Similarly, Kwerel (1977) shows that a linear regulation with a kink can incentivize firms to communicate their true cost function. As a reaction to Weitzman (1974), Spence (1977) analyzes general non-linear regulations. Spulber (1988) develops a model with production and externalities and shows that the full information optimum can only be attained if there are enough resources available to incentivice firms to communicate their true cost functions. Dasgupta and Spulber (1989) discuss various extensions of a pure quantity regulation. Weitzman (1978) shows that the optimal quadratic regulation is the weighted sum of the optimal price and the optimal quantity regulation. The paper at hand focuses on quadratic regulations as well. Weitzman (2015) argues in favor of a uniform price regulation (instead of a quantity regulation). Various problems tied to the private information about costs are discussed in Lewis (1996). Lewis and Sappington (1988) discuss optimal

[4] In terms of the taxonomy proposed by Berger and Marinacci (2020), the analysis conducted in this paper is based on classical expected utility theory.

price regulations with uncertainty about costs and benefits. Duggan and Roberts (2002) propose a mechanism that leads firms to internalize the effect of their quantity choice on social welfare. Rückert (2015) shows that a general regulation does not ex post Pareto-dominate a pure price or a pure quantity regulation (chapter 2) and that the welfare criterion (consumer surplus or total surplus) matters for optimal regulations (chapter 3). The observation that results depend crucially on the form of the welfare objective can also be transparently seen in the paper at hand. Metcalf (2020) proposes a carbon tax, that adjusts each year depending on the amount of emissions last year. This proposal is justified more formally by Ambec and Coria (2021).

Finally, there is an empirical literature applying the results of the previously described theoretical literature to analyze jointly the macroeconomic and environmental effects of different regulations (coined integrated assessment models). First of all there are the pioneering cost-benefit DICE models, summarized in Nordhaus and Boyer (2000). Pizer (2002) simulates kinked regulations in the Nordhaus (1994) DICE model and argues in favor of the flexibility of a kinked regulation over a quantity regulation (in the sense that the welfare gains are significant). Metcalf (2009) argues in favor of a carbon tax instead of a cap-and-trade system, based on previous empirical studies. Hassler et al. (2016) use a simplified DICE model to argue in favor of a – in their view – modest carbon tax. Rausch et al. (2011) use micro data and a computable general equilibrium model of the US economy to analyze the distributional impact of a carbon tax, based on the form of the rebate mechanism. Metcalf and Stock (2020) find no significant effect of a carbon tax on GDP in an OLS regression. Golosov et al. (2014a) develop a DSGE model and they show that, under certain assumptions, the optimal carbon tax does not depend on the whole distribution of uncertainty (but only the expected damage elasticity). They then simulate their model and find that the optimal carbon tax is significantly higher than those proposed in Stern and Stern (2007) and Nordhaus (2008), for the discount rates presumed in these reports. Borenstein et al. (2019) argue that California's certificate market is effectively characterized by a price floor and ceiling due to political interventions. Many empirical studies argue in favor of the flexibility of a kinked or other mixed regulations, a point that is also stressed in this paper. On the other, hand empirical studies are often even more restrictive than the theoretical literature in assuming a specific stochastic structure; in these empirical paper the different effects favoring one or the other regulation are not transparent.

3.2 Framework

The following model to study the regulation of multiple externalities under uncertainty is inspired by Weitzman (1974). As a motivation consider the following two situations: Energy can be produced form different sources such as wind, solar or geothermal energy.

Reductions in CO2 emissions can be realized in different sectors such as transportation, housing or industry. In both cases a regulator trying to align private and social objectives faces the challenge, that these quantities are not known exactly to the regulator (either because they are private information or because they are not known at the time of choosing the regulation). The situation above is captured by the following stylized model: There is a *regulator* who knows only the distribution of the private and the social objective. The regulator chooses a regulation to maximize the social objective plus the regulatory revenues in expectation. In addition, there is a *private agent* who knows the private objective exactly. The private agent chooses quantities to maximize the private objective minus the regulatory costs. The timing is as follows: *First*, the regulator announces the regulation and then the private agent chooses whether or not to be active in this market. *Second*, the private agent learns about the uncertainty and decides about quantities.

Formally, the problem of the regulator can be summarized as follows: Given the real-valued social objective $W(x, z)$, the real-valued private objective $S(x, z)$ and the real number λ, the problem is to choose a regulation $R(x)$ with values in the extended reals from a given class of functions to maximize

$$\mathbb{E}[W(x(z), z) + \lambda R(x(z))],$$

subject to the incentive compatibility constraint (IC)

$$S(x(z), z) - R(x(z)) \geq S(x, z) - R(x) \quad \text{for all} \quad x, z$$

and the participation constraint (PC)

$$\mathbb{E}[S(x(z), z) - R(x(z))] \geq 0,$$

where $x(z)$ is a vector denoting the quantities the private agent chooses and the random variable z denotes the uncertainty about the private and social objective.[5]

The production and consumption of $x = (\text{plastic}, \text{gasoline}, ...)$ is associated with a net welfare of $W(x(z), z) + \lambda R(x(z))$, which is uncertain. The planning authority cannot choose $x(z)$ directly, but tries to design the regulation $R(x)$ such that the induced quantity $x(z)$ maximizes expected welfare $\mathbb{E}[W(x(z), z) + \lambda R(x(z))]$ (note that this is different from inducing an expected quantity $\mathbb{E}[x(z)]$ to maximize expected welfare).

[5] For simplicity the model introduced above does not distinguish between externalities and commodities. More generally one could denote physical commodities by x and the (possibly multivalued) function mapping commodities to feasible levels of externalities by $f : x \mapsto f(x)$. Conversely one could denote externalities by x and the (possibly multivalued) function mapping externalities to feasible quantities of goods by $f : x \mapsto f(x)$. In both cases the social objective would be of the form $V(x, f(x), z)$. Defining $W(x, z) := V(x, f(x), z)$ nests this situation as a special case of the framework introduced above (analogously for the private objective).

In line with the previous literature it is assumed that the social and private objective can be approximated by second order polynomials, that is

$$W(x,z) = w_0(z) + x^T w_1(z) + x^T w_2(z)x,$$
$$S(x,z) = s_0(z) + x^T s_1(z) + x^T s_2(z)x,$$

where $w_0(z), s_0(z)$ are scalars, $w_1(z), s_1(z)$ are vectors and $w_2(z), s_2(z)$ are symmetric matrices. $w_1(z)$ and $s_1(z)$ are the intercepts of the marginal social and private objectives; $w_2(z)$ and $s_2(z)$ are the slopes of the marginal social and private objectives. For future reference define $\tilde{w}_k(z) := w_k(z) + \lambda s_k(z), k = 0, 1, 2$ and $\tilde{W} := W + \lambda S$.[6] As for a standard social welfare function $W(x,z)$ is assumed to be an increasing and concave function of x. For the private objective $S(x,z)$ there are numerous interpretations possible: If $S(x,z)$ corresponds to consumption utility as in Laffont (1977), then $S(x,z)$ should be increasing and concave in x; if $-S(x,z)$ corresponds to production costs as in Weitzman (1974), then $-S(x,z)$ should be increasing and convex in x; if $S(x,z)$ corresponds to the social surplus (consumption utility minus production costs), then $S(x,z)$ should be increasing and concave in x.[7] What is needed for the subsequent analysis, is that the incentive compatibility constraint on $x(z)$ can be equivalently characterized by the following first order condition

$$\nabla_x S(x(z), z) = \nabla_x R(x(z))$$

and this will be assumed from now on. The next two sections will introduce various classes of regulations. As a preliminary example consider a quadratic regulation of the form

$$R(x) = r + x^T p + (x - \bar{x})^T q(x - \bar{x}),$$

for a fixed payment r, a price vector p, a vector of target quantities $\bar{x}$ and a symmetric matrix of penalizing weights q. If q is small (large), this resembles a price (quantity) regulation. Sometimes it is easier to work with the following equivalent formulation of a quadratic regulation

$$R(x) = r_0 + x^T r_1 + x^T r_2 x,$$

[6] The i-th entry of the vector $s_1(z)$ is denoted by $s_{1[i]}(z)$ and the ij-th entry of the matrix $s_2(z)$ is denoted by $s_{2[ij]}(z)$. To simplify notation the dependency on z will often be suppressed, e.g. I will write s_1 instead of $s_1(z)$. Analogously for w_1 and w_2. For a matrix a, the matrix transpose and matrix inverse are denoted by a^T and a^{-1}, respectively.

[7] Of course, W might be partly determined by S, but the general formulation imposes no restriction: It could be the case that 'experienced utility' W is only correlated with 'decision utility' S (without any causal relation).

for a scalar r_0, a vector r_1 and a symmetric matrix r_2. Ignoring the participation constraint and assuming the validity of first order conditions, the private agent will choose

$$x(z) = -\frac{1}{2}\left(r_2 - s_2(z)\right)^{-1}\left(r_1 - s_1(z)\right).$$

Because the participation constraint will be binding, the problem of the regulator can be summarized as follows: choose r_1 and r_2 to maximize

$$\mathbb{E}\left[\tilde{W}\left(-\frac{1}{2}\left(r_2 - s_2(z)\right)^{-1}\left(r_1 - s_1(z)\right), z\right)\right].$$

The next two sections will analyze problems of this kind in detail. As a last bit of notation denote by

$$C[z_1, \ldots, z_n] := \mathbb{E}\left[(z_1 - \mathbb{E}[z_1]) \cdots (z_n - \mathbb{E}[z_n])\right]$$

the central mixed moment of the random variables $z_1, \ldots, z_n$. For example, $V[z_1] := C[z_1, z_1]$ denotes the variance of z_1, $C[z_1, z_2]$ the covariance of z_1, z_2, $C[z_1, z_2, z_3]$ the (non-standardized) coskewness of z_1, z_2, z_3 and $C[z_1, z_2, z_3, z_4]$ the (non-standardized) cokurtosis of z_1, z_2, z_3, z_4.

3.3 Single Good Case

The analysis of a single externality under uncertainty is the standard case in the literature following Weitzman (1974). In the single good case x is a scalar.

This section introduces three types of regulations: a price regulation, a quantity regulation and a quadratic regulation, nesting the first two cases. After deriving optimal regulations within a class of regulation (e.g., the optimal price regulation), optimal regulations will be compared between different classes of regulations (i.e., the welfare under the optimal price regulation vs. the welfare under the optimal quantity regulation). Finally, the cost-benefit-analysis in Weitzman (1974) will be studied as a special case.

3.3.1 Optimal Regulations

This subsection analyses the optimal price, quantity and quadratic regulations.

Price Regulation A single good price regulation takes the form

$$R(x) = r + px$$

for some scalars r and p. Here r denotes a lump-sum payment (or transfer, if r is negative) of the private agent and p denotes the price the private agent has to pay per unit of externality he or she emits. For CO2-emissions this regulation is called a carbon tax. The level of the lump-sum payment is not of much interest, because it just adjusts to satisfy the participation constraint with equality.

Lemma 4 *The optimal single good price regulation is given by*

$$p^* = \frac{\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}] - \mathbb{E}[\tilde{w}_1 s_2^{-1}]}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}.$$

If $s_2(z)$ is stochastically independent of the other parameters, this expression simplifies to

$$p^* = \mathbb{E}[s_1] - \frac{\mathbb{E}[\tilde{w}_1]\mathbb{E}[s_2^{-1}]}{\mathbb{E}[\tilde{w}_2]\mathbb{E}[s_2^{-2}]} + \frac{C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}.$$

Proof: See appendix.

Note that while the price regulation p^* is deterministic, the induced quantity $x(z) = \frac{1}{2}s_2(z)^{-1}\left(p^* - s_1(z)\right)$ will be random. From the first two terms on the right hand side of the above equation one can see that the optimal price regulation induces the private agent to choose quantities that maximize the social instead of the private objective: From a private perspective the relevant ratio is s_1/s_2, from a social perspective $\tilde{w}_1/\tilde{w}_2$. Therefore the price regulation corrects the private behavior for these ratios. The third term captures an additional channel an optimal price regulation should take into account: If the slope of the marginal social objective $\tilde{w}_2$ tends to be low when the intercept of the marginal private objective s_1 tends to be high, then c.p. the optimal price should be higher to discourage the private agent from choosing high quantities.

Quantity Regulation A single good quantity regulation takes the form

$$R(x) = \begin{cases} r, & x = \bar{x} \\ \infty, & x \neq \bar{x} \end{cases}$$

for some scalars r and $\bar{x}$. Again, r denotes a lump-sum payment and $\bar{x}$ a target quantity. For CO2-emissions this regulation is called a certificate market. This can be seen as the limiting case of a "soft" quantity regulation $R(x) = r + q(x - \bar{x})^2$ for $q \to \infty$. This case will be studied in the next paragraph.

Lemma 5 *The optimal single good quantity regulation is given by*

$$\bar{x}^* = -\frac{\mathbb{E}[\tilde{w}_1]}{2\mathbb{E}[\tilde{w}_2]}.$$

Proof: See appendix.

Naturally, the induced quantity will coincide with the quantity regulation, $x(z) = \bar{x}^*$. As was mentioned before, the relevant ratio from a welfare perspective is $\tilde{w}_1/\tilde{w}_2$. The best a quantity regulation can do is set the quantity equal to the ratio of the expected values of these parameters.

Quadratic Regulation A single good quadratic regulation takes the form

$$R(x) = r + px + q(x - \bar{x})^2$$

for some scalars r, p, q and $\bar{x}$. Note that for $q = 0$ and $q \to \infty$ this formulation nests a pure price and a pure quantity regulation.[8] For a finite value of the weighting factor q the last term can be seen as a "soft" quantity regulation: Deviating marginally from the target quantity $\bar{x}$ is associated with a cost of $2q$ (instead of an infinite cost for a "strict" quantity regulation). Sometimes it is easier to work with the following equivalent formulation of a quadratic regulation,

$$R(x) = r_0 + r_1 x + r_2 x^2$$

for some scalars r_0, r_1 and r_2. r_1 corresponds here to a base price and r_2 to a variable price, that increases with the quantity.

Lemma 6 *For $s_2(z)$ deterministic, the optimal single good quadratic regulation is given by*

$$\begin{aligned}
r_1^* &= \frac{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1^2] - \mathbb{E}[\tilde{w}_1 s_1]\mathbb{E}[\tilde{w}_2 s_1]}{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1] - \mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_1 s_1]} \\
&= \mathbb{E}[s_1] - \mathbb{E}[\tilde{w}_1]\frac{V[s_1] + \frac{C[\tilde{w}_2, s_1, s_1]}{\mathbb{E}[\tilde{w}_2]} - \frac{C[\tilde{w}_1, s_1]}{\mathbb{E}[\tilde{w}_1]}\frac{C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}}{C[\tilde{w}_1, s_1] - \mathbb{E}[\tilde{w}_1]\frac{C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}}, \\
r_2^* &= \mathbb{E}[s_2] + \frac{\mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_2 s_1^2] - \mathbb{E}[\tilde{w}_2 s_1]^2}{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1] - \mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_1 s_1]} \\
&= \mathbb{E}[s_2] - \mathbb{E}[\tilde{w}_2]\frac{V[s_1] + \frac{C[\tilde{w}_2, s_1, s_1]}{\mathbb{E}[\tilde{w}_2]} - \frac{C[\tilde{w}_2, s_1]^2}{\mathbb{E}[\tilde{w}_2]^2}}{C[\tilde{w}_1, s_1] - \mathbb{E}[\tilde{w}_1]\frac{C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}}.
\end{aligned}$$

Proof: See appendix.

[8] Of course, one could also use other penalty functions like $q \cdot \mathbb{1}(x \neq \bar{x})$ or asymmetric ones like $q \cdot \max(x - \bar{x}, 0)$ studied by Roberts and Spence (1976). For reasons of tractability, this paper focuses on quadratic regulations.

Note that it was necessary to assume that $s_2(z)$ is deterministic.[9] Although this is not an innocuous assumption (as one of the three welfare effects introduced later will be null), the formula for the optimal quadratic regulation provides some insights. To facilitate the discussion of this result take note of the following

Corollary 3 *If $s_2(z)$ is deterministic, we have under the optimal single good quadratic regulation*

$$x(z) - \mathbb{E}[x(z)] = \frac{\mathbb{E}[s_1] - s_1}{2\mathbb{E}[\tilde{w}_2]} \cdot \frac{C[\tilde{w}_1, s_1] - \mathbb{E}[\tilde{w}_1]\frac{C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}}{V[s_1] + \frac{C[\tilde{w}_2, s_1, s_1]}{\mathbb{E}[\tilde{w}_2]} - \frac{C[\tilde{w}_2, s_1]^2}{\mathbb{E}[\tilde{w}_2]^2}}.$$

The corollary states that the mean deviation of the optimal quantity should be equal to the mean deviation of the intercept of the marginal private objective times a weighting factor. To simplify further, assume first that $\tilde{w}_2$ and s_1 are stochastically independent. In that case the formulas above simplify to

$$r_k^* = \mathbb{E}[s_k] - \mathbb{E}[\tilde{w}_k] \cdot \frac{V[s_1]}{C[\tilde{w}_1, s_1]}, \quad k = 1, 2,$$
$$x(z) - \mathbb{E}[x(z)] = \frac{\mathbb{E}[s_1] - s_1}{2\mathbb{E}[\tilde{w}_2]} \cdot \frac{C[\tilde{w}_1, s_1]}{V[s_1]}.$$

For this simple case the rationale of the regulator for choosing the optimal regulation can be decomposed into two multiplicative effects: a variance effect and a covariance effect. Because the sign of this ratio is solely determined by the sign of the correlation between the intercepts, it is helpful to discuss these two situations separately.

Variance effect: For a positive ratio, i.e. $C[\tilde{w}_1, s_1] > 0$, the following applies. The higher the variance of the intercept of the marginal private objective s_1, the lower (higher) the base price r_1 (variable price r_2). Intuitively, the more uncertain the intercept of the marginal private objective, the more the regulator should discourage private behavior by implementing a steep regulation. This can also be seen from Corollary 3: The higher the variance, the less the realized quantity $x(z)$ should deviate from its expected value $\mathbb{E}[x(z)]$. For a negative ratio, i.e. $C[\tilde{w}_1, s_1] < 0$, the results reverse, a higher variance leads to a higher (lower) base price (variable price). Intuitively, for a negative correlation the regulator wants the private agent to be able to react to the uncertainty and this implies a flat regulation.

Covariance effect: The higher the covariance between the intercepts $\tilde{w}_1$ and s_1, the higher (lower) the base price r_1 (variable price r_2). The intuition for this result is the same as in the last paragraph: For a small covariance the regulator wants the private

[9]For the validity of Lemma 6 it is necessary to assume that s_1 is a nondegenerate random variable. However, when the distribution of s_1 converges to a degenerate distribution, r_1^* converges to $\mathbb{E}[s_1] - \mathbb{E}[\tilde{w}_1]$ and r_2^* converges to $\mathbb{E}[s_2] - \mathbb{E}[\tilde{w}_2]$, mimicking an optimal quantity regulation.

agent to be able to react to the uncertainty and this implies a flat regulation. Again, this result can also transparently be seen in Corollary 3.

General case: For the general case with a non-trivial relationship between $\tilde{w}_2(z)$ and $s_1(z)$ stated in Lemma 6 and Corollary 3, the following additional effects have to be taken into account. The variance effect for the base price r_1 is no longer necessarily positive, as a positive coskewness between $\tilde{w}_2, s_1$ and s_1 and an opposite sign of the covariances between $\tilde{w}_1, s_1$ and $\tilde{w}_2, s_1$ can drive the variance effect negative (for the variable price a non-zero covariance between $\tilde{w}_2, s_1$ contributes negatively to the variance effect). Intuitively, the coskeweness and the additional covariances can lower (higher) the base price r_1 (variable price r_2) compared to the simpler case discussed before, because a quantity regulation dampens simultaneous large variations in the slope of the social marginal objective $\tilde{w}_2$ and the intercept of the private marginal objective s_1. The covariance has to be corrected for another covariance term: In addition to the covariance between intercepts $\tilde{w}_1$ and s_1, the covariance between the slope of the social marginal objective $\tilde{w}_2$ and the intercept of the private marginal objective s_1 has to be taken into account. However, qualitatively the analysis remains unchanged: The denominator measures the (weighted) sum of the covariances.

3.3.2 Coefficient of Comparative Advantage

In the last subsection optimal regulations were derived. Although it is clear that a quadratic regulation is always weakly superior to a pure price or a pure quantity regulation, the comparison between these two extreme cases is prominently debated in the academic literature as well as in the political sphere. For this reason I study the coefficient of comparative advantage, as introduced in Weitzman (1974). For a regulation R and the associated quantity $x(z, R)$, denote by

$$\mathbb{E}\tilde{W}^R := \mathbb{E}\tilde{W}[x(z, R), z]$$

the expected welfare under regulation R and finally for two regulations R, R'

$$\Delta^{R;R'} := \mathbb{E}\tilde{W}^R - \mathbb{E}\tilde{W}^{R'}$$

the coefficient of comparative advantage. With a slight abuse of notation I denote the price, quantity and quadratic regulation by $R = p$, $R = \bar{x}$ and $R = (r_1, r_2)$, respectively. As was shown before, price and quantity regulations are special cases of a quadratic regulation. For this reason this subsection focuses on the welfare difference between a price and a quantity regulation.

Proposition 2 *For single good regulations, we have*

$$\Delta^{p;\bar{x}} = \text{ quantity effect } + \text{ variance effect } + \text{ covariance effect},$$

where

$$\begin{aligned}
\textit{quantity effect } &:= \frac{1}{4}\left(\frac{\mathbb{E}[\tilde{w}_1]^2}{\mathbb{E}[\tilde{w}_2]} - \frac{\mathbb{E}[\tilde{w}_1 s_2^{-1}]^2}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}\right), \\
\textit{variance effect } &:= \frac{1}{4}\left(\mathbb{E}[\tilde{w}_2 s_1^2 s_2^{-2}] - \frac{\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}]^2}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}\right), \\
\textit{covariance effect } &:= -\frac{1}{2}\left(\mathbb{E}[\tilde{w}_1 s_1 s_2^{-1}] - \frac{\mathbb{E}[\tilde{w}_1 s_2^{-1}]\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}]}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}\right).
\end{aligned}$$

If $s_2(z)$ is stochastically independent of the other parameters, these three effects simplify to

$$\begin{aligned}
\textit{quantity effect } &= \frac{1}{4}\frac{V[s_2^{-1}]}{\mathbb{E}[s_2^{-2}]}\frac{\mathbb{E}[\tilde{w}_1]^2}{\mathbb{E}[\tilde{w}_2]}, \\
\textit{variance effect } &= \frac{1}{4}\mathbb{E}[s_2^{-2}]\left(\mathbb{E}[\tilde{w}_2]V[s_1] - \frac{C[\tilde{w}_2, s_1]^2}{\mathbb{E}[\tilde{w}_2]} + C[\tilde{w}_2, s_1, s_1]\right), \\
\textit{covariance effect } &= -\frac{1}{2}\mathbb{E}[s_2^{-1}]\left(C[\tilde{w}_1, s_1] - \frac{\mathbb{E}[\tilde{w}_1]C[\tilde{w}_2, s_1]}{\mathbb{E}[\tilde{w}_2]}\right).
\end{aligned}$$

Proof: See appendix.

Analogously to the discussion of the optimal quadratic regulation, I will first assume that $\tilde{w}_2$ and s_1 are stochastically independent. In that case the formulas above simplify to

$$\begin{aligned}
\text{quantity effect } &= \frac{1}{4}\frac{V[s_2^{-1}]}{\mathbb{E}[s_2^{-2}]}\frac{\mathbb{E}[\tilde{w}_1]^2}{\mathbb{E}[\tilde{w}_2]}, \\
\text{variance effect } &= \frac{1}{4}\mathbb{E}[s_2^{-2}]\mathbb{E}[\tilde{w}_2]V[s_1], \\
\text{covariance effect } &= -\frac{1}{2}\mathbb{E}[s_2^{-1}]C[\tilde{w}_1, s_1],
\end{aligned}$$

inspiring the labeling of the three effects.

Quantity effect: The quantity effect works unambiguously in favor of the quantity regulation. This effect measures how good the price regulation is on average in targeting a given quantity. Only when the inverse slope of the marginal private objective s_2 is known, the price regulation is not at a disadvantage. Conversely, the higher $V[s_2^{-1}]$ the higher the welfare loss due to the quantity effect. Intuitively, the additional 'slope uncertainty' introduced by a price regulation compared to a quantity regulation always leads to a welfare loss because it becomes harder to target a given quantity. Note that $\mathbb{E}[\tilde{w}_1]^2/(4\mathbb{E}[\tilde{w}_2])$ is the welfare under a pure quantity regulation.

Variance effect: The variance effect works unambiguously in favor of the quantity regulation. This effect measures the welfare cost of using an inherently uncertain policy instrument, i.e. the price regulation. Only when the intercept of marginal welfare s_1 is known, the price regulation is not at a disadvantage. Conversely, the higher $V[s_1]$ the higher the welfare loss due to the variance effect. Intuitively, the additional 'intercept uncertainty' introduced by a price regulation compared to a quantity regulation always leads to a welfare loss because uncontrollable deviations from the targeted quantity are introduced.

Covariance effect: If the intercepts of the marginal social and private objectives $\tilde{w}_1$ and s_1 are negatively correlated, the covariance effect works in favor of the price regulation (and vice versa for a positive correlation). This effect measures the potential welfare gains from a price regulation that can exploit the relationship between the social objective and the private objective. By fixing a price instead of a quantity, the regulator allows the private agent to adjust their behavior in response to the realized uncertainty. Intuitively, this is a good idea, when the agent reacts to this information in the 'right' direction and a bad idea, if the agent reacts in the 'wrong' direction. The higher the covariance, the stronger the effect (in either direction). Only when there is no relation at all between social and private objective, this covariance effect vanishes.

Total effect: The covariance effect has to be sufficiently positive to counteract the negative quantity and variance effects to make the price regulation superior. That is, the welfare cost from introducing an additional source of uncertainty has to be lower than the increase in welfare from utilizing the information gain due to the statistical relationship between private and social objective.

This simple reasoning is only valid when $s_2(z)$ is stochastically independent of the other variables and $\tilde{w}_2(z)$ is stochastically independent of $s_1(z)$. Note, however, that even this simple case is much more general than Weitzman (1974) and unifies the seemingly disparate results in Weitzman (1974); Laffont (1977) and others. If one weakens the second requirement (as in Proposition 2), the following additional effects have to be taken into account:

The *quantity effect* is unaffected by this generalization.

The *variance effect* has to be corrected for two additional terms: A covariance term working unambiguously in favor of a price regulation and an ambiguous coskewness term. Both of these terms are related to the fact that while introducing intercept uncertainty comes at a welfare cost ($V[s_1] > 0$), the correlation between the slope of the social marginal objective $\tilde{w}_2$ and the intercept of the private marginal objective s_1 mitigates this effect whereas the coskewness between the aforementioned intercept and slope has an ambiguous effect: If the coskewness is positive, the price regulation is c.p. preferable because the price regulation can utilize simultaneous large variations in the slope of the social marginal objective and the intercept of the private marginal objective. The correction for these additional effects makes it possible that the total variance effect works in favor of a price regulation.

The *covariance effect* has to be corrected for another covariance term: In addition to the covariance between intercepts $\tilde{w}_1$ and s_1, the covariance between the slope of the social marginal objective $\tilde{w}_2$ and the intercept of the private marginal objective s_1 has to be taken into account. However, qualitatively the analysis remains unchanged: If the intercept or the slope of the marginal social objective and the intercept of the marginal private objectives are negatively correlated, the covariance effect works in favor of the price regulation (and vice versa for a positive correlation).

The *total effect* can now be positive, i.e. in favor of a price regulation, for two reasons: Because the variance effect and/or the covariance effect are sufficiently positive to counteract the remaining negative effect(s). Intuitively, there is more room for a price regulation to be advantageous, because it can potentially exploit more of the statistical relationship between the social and private objective (that is, it can exploit the statistical relationship between $\tilde{w}_2$ and s_1 in addition to the relationship between $\tilde{w}_1$ and s_1).

For the most general case in Proposition 2, all three effects have to be corrected for the additional stochastic relationship with $s_2(z)$. In particular, also the quantity effect could be positive, if $\mathbb{E}[\tilde{w}_2 s_2^{-2}]$ is small and negative and $\mathbb{E}[\tilde{w}_1 s_2^{-1}]$ is large in absolute values.

3.3.3 Special Case: Cost-Benefit-Analysis

In the Weitzman (1974) model welfare is given by

$$W(x, z) = T(x, z) + S(x, z)$$

with (at least) two possible interpretations:

i) S is (the negative of) a private cost function and T a private benefit function. For this interpretation choosing p amounts to a producer price regulation. This is the original Weitzman (1974) setup.

ii) S is a private benefit function and T (the negative of) a private cost function. For this interpretation choosing p amounts to a consumer price regulation. This is what Laffont (1977) calls the dual case to the original Weitzman (1974) setup.

Note that the regulator here really has to choices: First they can choose what behavior they want to regulate (consumers or producers) and then how they want to regulate (price or quantity). With this more specialized setup of a cost-benefit-analysis one can derive

Corollary 4 *If $s_2(z), t_2(z)$ are deterministic, $s_2(z), t_2(z)$ are stochastically independent from $s_1(z)$ and $\lambda = 0$, then we have for single good regulations:*

$$\Delta^{p;\bar{x}} = \textit{quantity effect} + \textit{variance effect} + \textit{covariance effect},$$

where

$$\begin{aligned} \textit{quantity effect} &:= 0, \\ \textit{variance effect} &:= \frac{s_2 + t_2}{4s_2^2} V[s_1], \\ \textit{covariance effect} &:= -\frac{1}{2s_2} C[s_1 + t_1, s_1]. \end{aligned}$$

The total effect can therefore be written as

$$\Delta^{p;\bar{x}} = \frac{V[s_1]t_2}{4s_2^2} - \frac{V[s_1] + 2C[t_1, s_1]}{4s_2}.$$

Of course this corollary could as easily be formulated for the general case. However, to be comparable, the parametric assumptions are chosen to be as close to Weitzman (1974) as possible. The total effect is exactly the same as in Weitzman (1974) on page 485, footnote 1: If the covariance between benefits and costs is zero, then a price regulation is superior to a quantity regulation iff the slope of marginal costs is bigger than the slope of marginal benefits. The intuition for this result is quite simple: A quantity regulation is better iff deviations from the optimal quantity are associated with large welfare losses, i.e., iff marginal benefits change quickly. Conversely, a price regulation is better iff deviations from a fixed value of marginal costs are associated with large welfare losses, i.e., iff marginal costs change quickly.

As is apparent from Proposition 2, this intuition can be misleading if one looks at the general case and the contributions of the three different effects are not transparent in Weitzman (1974)'s result. In Weitzman (1974) i) welfare is given by the difference between benefits and costs, ii) the intercepts of marginal costs and benefits are uncertain but uncorrelated and iii) the (producer) price regulation determines marginal costs. However, i) results change for alternative (welfarist) approaches, ii) additional effects occur for uncertain slopes and correlations (as is already mentioned in Weitzman (1974)) and iii) results reverse for a (consumer) price regulation determining marginal benefits (as was already noted by Laffont (1977)).

The framework proposed in this paper makes the contribution of the different effects transparent and uncovers the underlying logic behind the coefficient of comparative advantage: At first sight using an uncertain policy instrument and introducing additional uncertainty is always a bad idea and a quantity regulation is the superior instrument compared to a price regulation (quantity and variance effect). However, a price regulation can, under certain circumstances, exploit the informational advantage the private agent has, to increase welfare (covariance effect). The regulator has to balance the cost of using an uncertain policy instrument with the potential benefit of exploiting the statistical relationship between private and social objective.

3.4 Multiple Goods Case

This section extends the previous one-good analysis to two goods, i.e. x is a two-dimensional vector. However many results can be easily extended to an arbitrary number of goods. Throughout this section the focus lies on highlighting the differences between the multiple goods and the single good case.

In addition to the types of regulations studied before – price regulation, quantity regulation, quadratic regulation – the total quantity regulation is introduced. Furthermore, one has to distinguish for the first three types of regulations between differential and uniform regulations.

After deriving optimal regulations within a class of regulation (e.g., the optimal differential price regulation), optimal regulations will be compared between different classes of regulations (e.g., the welfare under the optimal uniform price regulation vs. the welfare under the optimal total quantity regulation). Finally, the case of atmospheric externalities will be studied as a special case.

3.4.1 Optimal Regulations

This subsection analyses the optimal price, quantity, total quantity and quadratic regulations. To simplify the exposition, it is often assumed that $s_2(z)$ is a diagonal matrix. E.g., for the case of S representing a cost function, this assumption implies that production is separable between different goods. The caveat "if all relevant matrix inverses exist" applies implicitly to all equality signs between matrices in the following section.

Price Regulation A two goods price regulation takes the form

$$R(x) = r + x^T p = r + p_1 x_1 + p_2 x_2$$

for some scalar r and a vector p. For $p_1 \neq p_2$ this is a *differential* price regulation and for $p_1 = p_2 =: p_0$ a *uniform* price regulation. Here r denotes a lump-sum payment (or transfer, if r is negative) of the private agent and p denotes the price the private agent has to pay per unit of externality he or she emits. Empirically, this regulation corresponds to the proposals of using sector-specific or homogeneous carbon taxes.

Lemma 7 *The optimal multiple goods differential price regulation is given by*

$$p^* = \mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\left(\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}s_1] - \mathbb{E}[s_2^{-1}\tilde{w}_1]\right).$$

Proof: See appendix.

Note that the formula for the optimal differential price regulation is formally identical to the formula for the optimal single good price regulation. In addition, this formula is valid for an arbitrary number of goods. However, due to the non-commutativity of matrix multiplication the ordering of parameters is important and behind the first term hides a complicated matrix inverse. The appendix derives a formula where the matrix multiplications are carried out for the two goods case and s_2 diagonal. Compared to the single good price regulation, the multiple goods differential price regulation can potentially exploit more of the intra-sectoral statistical relationship between parameters: The price regulation allows the private agent to act on the informational advantage he or she has; for the multiple goods case, the informational advantage is potentially greater than for the single good case.

Lemma 8 *The optimal multiple goods uniform price regulation for $s_2(z)$ diagonal is given by*

$$p_0^* = -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right] - \mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}{\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}.$$

Proof: See appendix.

Again, this formula is very similar to the one for the single good case. Compared to the single good case, the price implemented should be higher (lower) if the cross-derivative $\tilde{w}_{2[12]}$ is positive (negative). Intuitively, the regulator wants to discourage the private agent less overall (in choosing high quantities) if the marginal welfare of good 1 increases in the quantity of good 2.

Quantity Regulation A two goods quantity regulation takes the form

$$R(x) = \begin{cases} r, & x = \bar{x} \\ \infty, & x \neq \bar{x} \end{cases},$$

for some scalar r and a vector $\bar{x}$. For $\bar{x}_1 \neq \bar{x}_2$ this is a *differential* quantity regulation and for $\bar{x}_1 = \bar{x}_2 =: \bar{x}_0$ a *uniform* quantity regulation. Again, r denotes a lump-sum payment and $\bar{x}$ target quantities. For CO2-emissions this regulation can be seen as sector-specific (or country-specific) certificate markets. For the differential quantity regulation there is no trade of certificates between different sectors allowed. This can be seen as the limiting case of a "soft" quantity regulation $R(x) = r + (x - \bar{x})^T q(x - \bar{x}) = r + q_{11}(x_1 - \bar{x}_1)^2 + q_{22}(x_2 - \bar{x}_2)^2 + 2q_{12}(x_1 - \bar{x}_1)(x_2 - \bar{x}_2)$ for $q_{11} = q_{22} \to \infty$. This case will be studied in the last paragraph.

Lemma 9 *The optimal multiple goods differential quantity regulation is given by*

$$\bar{x}^* = -\frac{1}{2}\mathbb{E}[\tilde{w}_2]^{-1}\mathbb{E}[\tilde{w}_1].$$

Proof: See appendix.

Note that the formula for the optimal differential quantity regulation is formally identical to the formula for the optimal single good quantity regulation. In addition, this formula is valid for an arbitrary number of goods. However, due to the non-commutativity of matrix multiplication the ordering of parameters is important and behind the first term hides a matrix inverse. The appendix derives a formula where the matrix multiplications are carried out for the two goods case. Compared to the single good quantity regulation, the multiple goods differential quantity regulation takes the cross-derivative of welfare $\tilde{w}_{2[12]}$ into account: Depending on the exact interplay between the parameters, the differential quantity regulation might be more or less restrictive than the single good quantity regulation.

Lemma 10 *The optimal multiple goods uniform quantity regulation is given by*

$$\bar{x}_0^* = -\frac{\mathbb{E}[\tilde{w}_{1[1]} + \tilde{w}_{1[2]}]}{2\mathbb{E}[\tilde{w}_{2[11]} + \tilde{w}_{2[22]} + 2\tilde{w}_{2[12]}]}.$$

Proof: See appendix.

Again, this formula is very similar to the one for the single good case. Compared to the single good case, the quantity implemented should be higher (lower) if the cross-derivative $\tilde{w}_{2[12]}$ is positive (negative). Intuitively, the regulator wants to set the uniform quantity higher, if the marginal welfare of good 1 increases in the quantity of good 2. That is, the reasoning behind adjusting the regulation in the multiple goods case is very similar between the price and the quantity regulation.

Total Quantity Regulation A two goods total quantity regulation takes the form

$$R(x) = \begin{cases} r, & x_1 + x_2 = \bar{X} \\ \infty, & x_1 + x_2 \neq \bar{X} \end{cases},$$

for some scalars r and $\bar{X}$. Again, r denotes a lump-sum payment and $\bar{X}$ a total quantity target. For CO2-emissions this regulation can be seen as a common certificate market. Note the difference to a differential or a uniform quantity regulation: In these cases the quantities are fixed for each individual sector. For a total quantity regulation only the deviation from a specified level of economy-wide externalities is penalized. For the moment one can think of a single firm that operates in both sectors and directly faces the total quantity regulation; Section 3.5 shows how this regulation can be decentralized. This can be seen as the limiting case of a "soft" quantity regulation $R(x) = r + (x - \bar{x})^T q(x - \bar{x}) = r + q_{11}(x_1 - \bar{x}_1)^2 + q_{22}(x_2 - \bar{x}_2)^2 + 2q_{12}(x_1 - \bar{x}_1)(x_2 - \bar{x}_2)$ for $q_{11} = q_{22} = q_{12} \to \infty$.[10] This case will be studied in the last paragraph.

Lemma 11 *The optimal multiple goods total quantity regulation is given by*

$$\bar{X}^* = -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}} + \frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}.$$

Proof: See appendix.

This regulation can be seen as an intermediate case between a uniform price and a quantity regulation: With a price regulation the private agent has full control over the quantities of both goods. With a quantity regulation the private agent has no control over the individual quantities. With a total quantity regulation the private agent has no control over the total quantity, but can decide on the individual quantities to some degree. The optimal total quantity reflects this trade-off between setting a strict rule for the total quantity but allowing the private agent to allocate the total quantity between both goods in a resource efficient way. Note that the individual quantities are given by

$$x_k(\bar{X}, z) = \frac{s_{1[3-k]} - s_{1[k]} + 2s_{2[3-k,3-k]}\bar{X}}{2s_{2[11]} + 2s_{2[22]}}, \quad k = 1, 2,$$

and that the individual quantities are of course random. As can be seen from the lemma, a total quantity regulation is different from a quantity regulation because it can exploit the statistical relationship between the private and the social objective. Note, however,

[10]Note that for $q_{11} = q_{22} = q_{12} := \tilde{q}$ and $\bar{x}_1 + \bar{x}_2 =: \bar{X}$ the quadratic regulation can be written as $R(x) = r + \tilde{q}(x_1 + x_2 - \bar{X})^2$.

that for atmospheric externalities with $\tilde{w}_{1[1]} = \tilde{w}_{1[2]}$ and $\tilde{w}_{2[11]} = \tilde{w}_{2[22]} = \tilde{w}_{2[11]}$ (this case will be discussed in detail in the next section), the total quantity regulation reduces to a normal quantity regulation as the regulator cares only about total quantity from a welfare perspective. Similarly, the total quantity regulation reduces to a normal quantity regulation if the private objectives for both goods are identical. In that case the private agent will treat both goods identically and the regulator can affect the total quantity only.

Quadratic Regulation A two goods quadratic regulation takes the form

$$R(x) = r + x^T p + (x - \bar{x})^T q(x - \bar{x})$$

for some scalar r, vectors $p, \bar{x}$ and a symmetric matrix q. Again, r denotes a lump-sum payment, p a price vector, $\bar{x}$ a vector of target quantities and q a matrix of penalizing weights. Note that for $q = 0, q_{11} = q_{22} \to \infty$ and $q_{11} = q_{22} = q_{12} \to \infty$ this formulation nests a uniform and differential price regulation, a uniform and differential quantity regulation and a total quantity regulation, respectively. For a finite weighting matrix q the last term can be seen as a "soft" quantity regulation: deviating marginally from the target quantities $\bar{x}$ is associated with a cost of $2q$ (instead of an infinite cost for a "strict" quantity regulation). Sometimes it is easier to work with the following equivalent formulation of a quadratic regulation,

$$R(x) = r_0 + x^T r_1 + x^T r_2 x$$

for a scalar r_0, a vector r_1 and a symmetric matrix r_2. r_1 corresponds here to a base price vector and r_2 to a matrix of variable prices, that increases in quantities.

Lemma 12 *The optimal multiple goods quadratic regulation is implicitly characterized by the following system of equations:*

$$\begin{aligned}
&\mathbb{E}\left[(r_2 - s_2)^{-1}\tilde{w}_1\right] \\
=&\mathbb{E}\left[(r_2 - s_2)^{-1}\tilde{w}_2(r_2 - s_2)^{-1}(r_1 - s_1)\right], \\
&\mathbb{E}\left[(r_2 - s_2)^{-1}(r_1 - s_1)\tilde{w}_1^T(r_2 - s_2)^{-1}\right] \\
=&\mathbb{E}\left[(r_2 - s_2)^{-1}\left(\tilde{w}_2(r_2 - s_2)^{-1}(r_1 - s_1)(r_1 - s_1)^T\right)(r_2 - s_2)^{-1}\right].
\end{aligned}$$

Proof: See appendix.

This formula is valid for an arbitrary number of goods. Note that the first (second) equation refers to an equality of vectors (matrices). Instead of deriving the optimal quadratic regulation explicitly, it suffices here to state the system of first order conditions one has to solve to derive the optimal regulation. Compared to the single good case, one would have to impose much stronger assumptions to derive explicit solutions. The reason for this lies in the complicated statistical relationship between the social and private objective – for a given good and between different goods.

3.4.2 Coefficients of Comparative Advantage

In the last subsection optimal regulations were derived. It was argued that a quadratic regulation is always weakly superior to all other regulations introduced, as the other regulations are special cases of a quadratic regulation. Therefore the following section focuses on the comparison between these other regulations. Analogously to the single good case and Weitzman (1974), denote for a regulation R and the associated quantities $x(z, R)$ by

$$\mathbb{E}\tilde{W}^R := \mathbb{E}\tilde{W}[x(z, R), z]$$

the expected welfare under regulation R and finally for two regulations R, R'

$$\Delta^{R;R'} := \mathbb{E}\tilde{W}^R - \mathbb{E}\tilde{W}^{R'}$$

the coefficient of comparative advantage. With a slight abuse of notation I denote the differential price, uniform price, differential quantity, uniform quantity and total quantity regulation by $R = p$, $R = p_0$, $R = \bar{x}$, $R = \bar{x}_0$ and $R = \bar{X}$, respectively. For the two-goods case there are numerous coefficients one could calculate, e.g.,

i) Differential Price vs. Differential Quantity

ii) Uniform Price vs. Total Quantity

iii) Differential Price vs. Total Quantity

iv) Differential Quantity vs. Total Quantity

This paper will focus on iii) and iv) as these cases focus on the main conflict presented in the introduction: Under what circumstances is a common certificate market better than a sector-specific regulation (sector-specific taxes or sector-specific certificate markets). The first two cases are formally very similar to the single good case and show that the single good case naturally generalizes to the multiple goods case. The welfare difference between the optimal differential price (quantity) regulation and the optimal uniform price (quantity) regulation is always positive and therefore not of much interest in itself.

Proposition 3 *For multiple goods regulations, we have*

$$\Delta^{p;\bar{x}} = \; QE \; + \; VE \; + \; CE$$

where

$$\begin{aligned} QE \; &:= \frac{1}{4}\left(\mathbb{E}[\tilde{w}_1]^T\mathbb{E}[\tilde{w}_2]^{-1}\mathbb{E}[\tilde{w}_1] - \mathbb{E}[\tilde{w}_1^T s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1]\right), \\ VE \; &:= \frac{1}{4}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}s_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}s_1]\right), \\ CE \; &:= -\frac{1}{2}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1]\right). \end{aligned}$$

Proof: See appendix.

Note that this formula is completely analogous to the single good case. In addition, this formula is valid for an arbitrary number of goods. This case was already studied by Weitzman (1974), although in his more specialized model (see also Section 3.3.3). QE, VE and CE are abbreviations for the familiar quantity effect, variance effect and covariance effect. Again, one can impose restrictions on the statistical relationship between the parameters to discuss special cases. To facilitate the following discussion of the differences to the single good case, assume that s_2 is deterministic and that $\tilde{w}_2 s_2^{-1}$ and s_1 are uncorrelated (i.e. $\mathbb{E}[\tilde{w}_2 s_2^{-1}s_1] = \mathbb{E}[\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_1]$). In that case the formulas above simplify to

$$\begin{aligned} \text{QE} \; &= 0, \\ \text{VE} \; &= \frac{1}{4}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}s_1] - \mathbb{E}[s_1^T]\mathbb{E}[s_2^{-1}]\mathbb{E}[\tilde{w}_2]\mathbb{E}[s_2^{-1}]\mathbb{E}[s_1]\right), \\ \text{CE} \; &= -\frac{1}{2}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_1] - \mathbb{E}[s_1^T]\mathbb{E}[s_2^{-1}]\mathbb{E}[\tilde{w}_1]\right). \end{aligned}$$

The *quantity effect* measures the effect of the additional ‘slope uncertainty’ introduced by a price regulation (and is therefore null for s_2 deterministic).

The *variance effect* is related to the variance of s_1 and measures the additional ‘intercept uncertainty’ introduced by a price regulation. To see this more clearly, note that for a symmetric and deterministic matrix a one can write $\mathbb{E}[s_1^T a s_1] - \mathbb{E}[s_1^T]\mathbb{E}[a]\mathbb{E}[s_1] = \sum_{i,j} a_{ij}\mathbb{E}[s_{1[i]}s_{1[j]}] - a_{ij}\mathbb{E}[s_{1[i]}]\mathbb{E}[s_{1[j]}] = \sum_{i,j} a_{ij}C[s_{1[i]}, s_{1[j]}] = \sum_i a_{ii}V[s_{1[i]}] + 2\sum_{i<j} a_{ij}C[s_{1[i]}, s_{1[j]}]$. In contrast to the single good case, the new covariance terms can now contribute positively to the variance effect. This effect still relates to the variance of s_1 (and the variance of s_1 collects also the covariance between different entries of s_1) and is therefore different from the covariance term discussed in the following relating to the covariance between different vectors (the covariance between s_1 and $\tilde{w}_1$).

The *covariance effect* is related to the covariance between s_1 and $\tilde{w}_1$ and measures to which degree the private agent responds to new information in the 'right direction'. Already for the single good case this effect can support a price or a quantity regulation. For the multiple goods case there are now covariance terms between different entries of s_1 and $\tilde{w}_1$ present, analogously to the discussion of the variance effect.

The *total effect* again consists of the sum of the three effects discussed before. Compared to the single good case, the price regulation has more potential to be advantageous. The reason for this is the following: In the multiple goods case there is not only the problem of determining the overall level of externalities but also of allocating resources to different sectors. A differential quantity regulation is quite inflexible in handling this second task. A differential price regulation on the other hand, can, in principle, exploit the interdependence between different goods. However, that does not mean that the disadvantages of a price regulation discussed extensively for the single good case, are not also present for the multiple goods case. The total effect is again unclear and depends on the relative strength of the quantity, the variance and the covariance effect.

Proposition 4 *For multiple goods regulations, we have*

$$\Delta^{p_0;\bar{X}} = (QE_{p_0} - QE_{\bar{X}}) + (VE_{p_0} - VE_{\bar{X}}) + (CE_{p_0} - CE_{\bar{X}})$$

where

$$QE_{p_0} := -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]},$$

$$QE_{\bar{X}} := -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},$$

$$VE_{p_0} := \frac{1}{4}\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{1[1]}^2}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}s_{1[2]}^2}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}s_{1[1]}s_{1[2]}}{s_{2[11]}s_{2[22]}}\right]$$
$$-\frac{\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]},$$

$$VE_{\bar{X}} := \frac{1}{4}\mathbb{E}\left[\frac{\left(\tilde{w}_{2[11]} + \tilde{w}_{2[22]} - 2\tilde{w}_{2[12]}\right)\left(s_{1[2]} - s_{1[1]}\right)^2}{(s_{2[11]} + s_{2[22]})^2}\right]$$
$$-\frac{\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},$$

$$CE_{p_0} := -\frac{1}{2}\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}s_{1[2]}}{s_{2[22]}}\right]$$
$$+\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]},$$

$$CE_{\bar{X}} := \frac{1}{2}\mathbb{E}\left[\frac{\left(\tilde{w}_{1[1]} - \tilde{w}_{1[2]}\right)\left(s_{1[2]} - s_{1[1]}\right)}{s_{2[11]} + s_{2[22]}}\right]$$
$$-\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}.$$

Proof: See appendix.

This proposition is the other natural generalization of the single good case to the multiple goods case. To make the formulas more accessible, the quantity, variance and covariance effect are further broken down according to the welfare contribution of the different regulations. E.g., VE_{p_0} is the part of welfare under a uniform price regulation that corresponds to the variance effect. What makes this comparison different from the single good case, is the fact that both regulations can exploit the informational advantage of the private agent. The uniform price regulation allows the private agent to freely choose both quantities, while the total quantity regulation allows only for the privately determined distribution between sectors. This is reflected in all three effects:

The *quantity effect* for the uniform price regulation differs from the single good price regulation qualitatively only insofar, as a positive cross-derivative of the social objective $\tilde{w}_{2[12]}$ increases the welfare under a price regulation. This is also true for the total quantity regulation. As the quantity effects relates to the 'slope' uncertainty introduced by both regulations (note that also the total quantity regulation introduces slope uncertainty, in contrast to the uniform or differential quantity regulation), the interaction between the slopes of the marginal private objective with the social objective determines whether the uniform price or the total quantity regulation is superior.

The *variance effect* for the uniform price regulation is again qualitatively very similar to the single good case apart from the terms involving $\tilde{w}_{2[12]}$. This effect tends to be negative, as the uniform price regulation introduces additional 'intercept' uncertainty. However, compared to the single good price regulation the uniform price regulation has more room to be advantageous. The variance effect for the total quantity regulation is only non-zero if both the social and the private objective are not symmetrical.

The *covariance effect* for the uniform price regulation is again qualitatively very similar to the single good case apart from the terms involving $\tilde{w}_{2[12]}$. This effect is in general ambiguous and can contribute positively or negatively to the welfare effect due to the uniform price regulation (as for the single good case). The covariance effect for the total quantity regulation shows the qualitatively different mechanism of the total quantity regulation: The first term contributes positively to the welfare of the total quantity regulation if the differences between the intercepts of the marginal social $\tilde{w}_{1[2]} - \tilde{w}_{1[1]}$ and private objective $s_{1[2]} - s_{1[1]}$ have the same sign (for a concave private objective). Intuitively, if the intercepts of the marginal social objectives are equal the regulator does not care where the reduction of emissions takes place and if the intercepts of the marginal private objectives are equal, the regulator cannot influence the allocation of the total quantity to the different sectors (via the intercepts). For the intermediate case, i.e., if the difference between the intercepts of the social objective tends to be positive when difference between the intercepts of the private objective tends to be positive, then the total quantity regulation contributes positively to welfare. This is because the total quantity regulation allows for the realization of the welfare gains of an efficient allocation of resources between sectors. Conversely, in the opposite case the private agent allocates the resources between sectors contrary to the wishes of the regulator. This reasoning applies similarly to the second effect, the relevant term is the second one in the nominator. Again, the signs of the difference between the intercepts of the marginal private objective $s_{1[2]} - s_{1[1]}$ and the difference $s_{2[22]}(\tilde{w}_{2[11]} - \tilde{w}_{2[12]}) - s_{2[11]}(\tilde{w}_{2[22]} - \tilde{w}_{2[12]})$ is decisive for the value of the total quantity regulation. Analogously to the discussion before, if these differences have the same sign, then the private agent uses its discretion in allocating the total quantity to the different sectors according to the will of the regulator. In that case, a total quantity regulation has a positive effect on welfare.

The *total effect* consists of the three effects discussed before. Because both regulations leave the private agent a large degree of freedom in choosing quantities, the quantity, variance and covariance effect are relatively complicated. Nevertheless the decomposition into these three (or six) effects clarifies the different arguments on has to contemplate when choosing one of the two regulations.

Proposition 5 *For multiple goods regulations, we have*

$$\Delta^{p;\bar{X}} = (QE_p - QE_{\bar{X}}) + (VE_p - VE_{\bar{X}}) + (CE_p - CE_{\bar{X}})$$

where

$$\begin{aligned}
QE_p &:= -\frac{1}{4}\mathbb{E}[\tilde{w}_1^T s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1],\\
QE_{\bar{X}} &:= -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},\\
VE_p &:= \frac{1}{4}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}s_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}s_1]\right),\\
VE_{\bar{X}} &:= \frac{1}{4}\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}+\tilde{w}_{2[22]}-2\tilde{w}_{2[12]})(s_{1[2]}-s_{1[1]})^2}{(s_{2[11]}+s_{2[22]})^2}\right]\\
&\quad - \frac{\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},\\
CE_p &:= -\frac{1}{2}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1]\right),\\
CE_{\bar{X}} &:= \frac{1}{2}\mathbb{E}\left[\frac{(\tilde{w}_{1[1]}-\tilde{w}_{1[2]})(s_{1[2]}-s_{1[1]})}{s_{2[11]}+s_{2[22]}}\right]\\
&\quad - \frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}.
\end{aligned}$$

Proof: See appendix.

This proposition gives a formal answer to the question under what circumstances sector-specific taxes are superior to a unified cross-sectoral certificate market. These two regulations differ in two dimensions: One is a price, the other a quantity regulation; one is a differential regulation, the other is not. To disentangle these two channels this proposition should be seen in conjunction with Proposition 4 that studies the differences between uniform regulations and the simple identity $\Delta^{p;\bar{X}} = \Delta^{p;p_0} + \Delta^{p_0;\bar{X}}$. Note that trivially $\Delta^{p;p_0} \geq 0$. Because the welfare effects of the second term $\Delta^{p_0;\bar{X}}$ were already discussed after Proposition 4, the following discussion focuses on the novel aspects of the comparison between a differential price and a total quantity regulation. As for the previous proposition, the quantity, variance and covariance effect are further broken down according to the welfare contribution of the different regulations. The appendix derives the welfare effects of a differential price regulation explicitly.

To prepare the discussion note that $\Delta^{p;p_0} = 0$ when the optimal differential price regulation recommends a uniform price, $p_1^* = p_2^*$. From the proof of Lemma 7, this is the case iff

$$\frac{\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right]}{\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]} = \frac{\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]}{\mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}.$$

To understand this condition, note that in the single good case the regulator wants to implement a quantity proportional to $\tilde{w}_1/\tilde{w}_2$. Both sides of this equation represent the best a price regulation can achieve when trying to implement the optimal quantity (see also the discussion after Lemma 4). Only when the contribution to welfare of both goods is equal, both prices should be equal. Conversely, the more both sides differ, the more optimal prices will differ and therefore the restriction to a uniform price will impose a significant welfare loss in this case.

The total welfare loss depends therefore on i) how symmetric both goods are, in the sense, that the above equality is fulfilled ($\Delta^{p;p_0}$) and ii) how large the welfare difference between the two uniform regulations is ($\Delta^{p_0;\bar{X}}$). The last term consists of course of the familiar quantity, variance and covariance effects.

Proposition 6 *For multiple goods regulations, we have*

$$\Delta^{\bar{x};\bar{X}} = QE + VE + CE$$

where

$$QE := -\frac{1}{4}\frac{\mathbb{E}[\tilde{w}_{1[1]}]^2\mathbb{E}[\tilde{w}_{2[22]}] + \mathbb{E}[\tilde{w}_{1[2]}]^2\mathbb{E}[\tilde{w}_{2[11]}] - 2\mathbb{E}[\tilde{w}_{1[1]}]\mathbb{E}[\tilde{w}_{1[2]}]\mathbb{E}[\tilde{w}_{2[12]}]}{\mathbb{E}[\tilde{w}_{2[11]}]\mathbb{E}[\tilde{w}_{2[22]}] - \mathbb{E}[\tilde{w}_{2[12]}]^2},$$

$$+\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},$$

$$VE := -\frac{1}{4}\mathbb{E}\left[\frac{\big(\tilde{w}_{2[11]} + \tilde{w}_{2[22]} - 2\tilde{w}_{2[12]}\big)\big(s_{1[2]} - s_{1[1]}\big)^2}{(s_{2[11]} + s_{2[22]})^2}\right]$$

$$+\frac{\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]},$$

$$CE := -\frac{1}{2}\mathbb{E}\left[\frac{\big(\tilde{w}_{1[1]} - \tilde{w}_{1[2]}\big)\big(s_{1[2]} - s_{1[1]}\big)}{s_{2[11]} + s_{2[22]}}\right]$$

$$+\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}.$$

Proof: See appendix.

Similar to the last proposition, this statement gives a formal answer to the question under what circumstances sector-specific certificate markets are superior to a unified cross-sectoral certificate market. Of course, in the first instance trade of certificates between the different sectors are forbidden. This offers another angle at the same question: Under what circumstances is a linkage of previously separated certificate markets beneficial. The same logic can also be applied to multiple countries instead of multiple sectors. This proposition is less complicated than the previous two propositions as only the total quantity regulation can exploit the statistical relationship between the private and the social objective. Again, the welfare difference between the two regulations can be decomposed into three effects[11]:

The *quantity effect* again relates to the uncertainty introduced by the slope of the marginal social objective. Note that even for deterministic slopes the quantity effect does not vanish. The reason for this is that the total quantity regulation has to perform a mixed calculation, even if it knows the private objective exactly: Given a total quantity regulation the private agent will choose individual quantities and these chosen quantities depend on the slope of the marginal private objective. The differential quantity regulation, on the other hand, controls individual quantities exactly and is therefore

[11] Alternatively, and analogous to the discussion of Proposition 5, one can also decompose the coefficient of comparative advantage as follows $\Delta^{\bar{x};\bar{X}} = \Delta^{\bar{x};p} + \Delta^{p;\bar{X}}$ and refer to previous propositions to explain the results.

independent of the private objective. A priori, it is not clear whether the quantity effect is positive or negative.

The *variance effect* is identical to $\mathrm{VE}_{\bar{X}}$ from the previous two propositions: It is only non-zero if neither the private nor the social objective is completely symmetrical.

The *covariance effect* is again identical to $\mathrm{CE}_{\bar{X}}$ from the previous two propositions: The contribution to total welfare depends on the differences between the intercepts of the marginal social objectives and the differences between the intercepts of the marginal private objectives. For an extensive discussion refer to Proposition 4.

The *total effect* consists of these three effects. Overall the question is to what degree the regulator cares about the individual quantities and to what degree the different regulations can implement these quantities. This question will also be discussed in detail for atmospheric externalities in the next subsection.

3.4.3 Special Case: Atmospheric Externalities

As an important special case, atmospheric externalities will be studied in detail. The defining feature of an atmospheric externality is, that from a welfare perspective, only the total amount of the externality matters. The leading example for an atmospheric externality is CO2 emissions: only the total amount of CO2 emissions in the atmosphere matters, not the exact source. Formally only the sum x_1+x_2 enters welfare, instead of the individual quantities x_1 and x_2. In terms of parameters this implies $w_{1[1]} = w_{1[2]} =: w_1$ and $w_{2[11]} = w_{2[22]} = w_{2[12]} =: w_2$ and we can write $W(x_1, x_2, z) = w_0 + w_1(x_1 + x_2) + w_2(x_1 + x_2)^2$.[12] Before turning to the various coefficients of comparative advantage, note that all quantity regulations are identical for $\lambda = 0$ (strictly speaking, the optimal differential quantity regulation is not well-defined because only the sum of individual quantities is pinned down). Therefore the following analysis will focus on the comparison between the uniform price and the total quantity regulation only. The expressions for the difference between the welfare of the uniform price and the total quantity regulation simplify considerably, as shown in the following

Corollary 5 *For multiple goods regulations, atmospheric externalities and $\lambda = 0$, we have*

$$\Delta^{p_0;\bar{X}} = \ QE \ + \ VE \ + \ CE$$

[12] Although w_1 and w_2 referred previously to vectors and matrices, this notation should not lead to confusion.

where

$$
\begin{aligned}
QE &:= \frac{1}{4}\left(\frac{\mathbb{E}[\tilde{w}_1]^2}{\mathbb{E}[\tilde{w}_2]} - \frac{\mathbb{E}\left[\tilde{w}_1\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)\right]^2}{\mathbb{E}\left[\tilde{w}_2\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)^2\right]}\right), \\
VE &:= \frac{1}{4}\left(\mathbb{E}\left[\tilde{w}_2\left(\frac{s_{1[1]}}{s_{2[11]}}+\frac{s_{1[2]}}{s_{2[22]}}\right)^2\right] - \frac{\mathbb{E}\left[\tilde{w}_2\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)\left(\frac{s_{1[1]}}{s_{2[11]}}+\frac{s_{1[2]}}{s_{2[22]}}\right)\right]^2}{\mathbb{E}\left[\tilde{w}_2\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)^2\right]}\right), \\
CE &:= -\frac{1}{2}\left(\mathbb{E}\left[\tilde{w}_1\left(\frac{s_{1[1]}}{s_{2[11]}}+\frac{s_{1[2]}}{s_{2[22]}}\right)\right] - \frac{\mathbb{E}\left[\tilde{w}_1\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)\right]\mathbb{E}\left[\tilde{w}_2\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)\left(\frac{s_{1[1]}}{s_{2[11]}}+\frac{s_{1[2]}}{s_{2[22]}}\right)\right]}{\mathbb{E}\left[\tilde{w}_2\left(\frac{1}{s_{2[11]}}+\frac{1}{s_{2[22]}}\right)^2\right]}\right)
\end{aligned}
$$

Proof: See appendix.

Note that the private objective enters all formulas in the forms $1/s_{2[11]}+1/s_{2[22]} =: \tilde{s}_{/2}$ and $s_{1[1]}/s_{2[11]} + s_{1[2]}/s_{2[22]} =: \tilde{s}_{1/2}$ only. With this more compact notation one can write

$$
\begin{aligned}
\text{QE} &= \frac{1}{4}\left(\frac{\mathbb{E}[\tilde{w}_1]^2}{\mathbb{E}[\tilde{w}_2]} - \frac{\mathbb{E}\left[\tilde{w}_1\tilde{s}_{/2}\right]^2}{\mathbb{E}\left[\tilde{w}_2\tilde{s}_{/2}^2\right]}\right), \\
\text{VE} &= \frac{1}{4}\left(\mathbb{E}\left[\tilde{w}_2\tilde{s}_{1/2}^2\right] - \frac{\mathbb{E}\left[\tilde{w}_2\tilde{s}_{/2}\tilde{s}_{1/2})\right]^2}{\mathbb{E}\left[\tilde{w}_2\tilde{s}_{/2}^2\right]}\right), \\
\text{CE} &= -\frac{1}{2}\left(\mathbb{E}\left[\tilde{w}_1\tilde{s}_{1/2}\right] - \frac{\mathbb{E}\left[\tilde{w}_1\tilde{s}_{/2}\right]\mathbb{E}\left[\tilde{w}_2\tilde{s}_{/2}\tilde{s}_{1/2}\right]}{\mathbb{E}\left[\tilde{w}_2\tilde{s}_{/2}^2\right]}\right).
\end{aligned}
$$

This formula is formally identical to the coefficient of comparative advantage in the single good case: $\tilde{s}_{/2}$ takes the role of $1/s_2$ and $\tilde{s}_{1/2}$ takes the role of s_1/s_2 in the single good case. Similarly to the discussion of the coefficient of comparative advantage for the single good case, it is useful to assume first that s_2 and $\tilde{w}_2$ are deterministic. In this case the three effects simplify to

$$\begin{aligned}
\text{QE} &= 0, \\
\text{VE} &= \frac{1}{4}\mathbb{E}\left[\tilde{w}_2\right] V\left[\frac{s_{1[1]}}{s_{2[11]}} + \frac{s_{1[2]}}{s_{2[22]}}\right] \\
&= \frac{1}{4}\mathbb{E}\left[\tilde{w}_2\right]\left(\frac{V[s_{1[1]}]}{s_{2[11]}^2} + \frac{V[s_{1[2]}]}{s_{2[22]}^2} + 2\frac{C[s_{1[1]}, s_{1[2]}]}{s_{2[11]}s_{2[22]}}\right), \\
\text{CE} &= -\frac{1}{2}C\left[\tilde{w}_1, \frac{s_{1[1]}}{s_{2[11]}} + \frac{s_{1[2]}}{s_{2[22]}}\right] \\
&= -\frac{1}{2}\left(\frac{C[\tilde{w}_1, s_{1[1]}]}{s_{2[11]}} + \frac{C[\tilde{w}_1, s_{1[2]}]}{s_{2[22]}}\right).
\end{aligned}$$

The *quantity effect* measures the effect of the additional 'slope uncertainty' introduced by a uniform price regulation (and is therefore null for s_2 deterministic).

The *variance effect* works unambiguously in favor of the total quantity regulation as it measures the additional 'intercept uncertainty' introduced by a uniform price regulation. As a new effect compared to the single good case a positive covariance between the intercepts of the marginal private objective in the different sectors works in favor of a total quantity regulation. Intuitively, if a high intercept of the private marginal objective in sector 1 goes hand in hand with a high intercept of the private marginal objective in sector 2, then a uniform price regulation introduces even more uncertainty to the quantities: Not only are the quantities random because of the random intercepts, but in addition the randomness in the intercepts is mutually reinforced. Put differently, a negative covariance works in favor of a uniform price regulation, because a higher quantity in sector 1 goes hand in hand with a lower quantity in sector 2 and the uncertainty over the total quantity is reduced.

The *covariance effect* is ambiguous and depends on the covariance between the intercepts of the marginal private and the social objective. Compared to the single good case there are now two covariance terms: the covariance between the intercept of the marginal private and the social objective in sector 1 and the covariance between the intercept of the marginal private and the social objective in sector 2. If both covariance terms have the same sign, then the same intuition as for the single good case applies. Interestingly, if the covariance terms have an opposite sign but have similar absolute values (weighted by the appropriate slopes), then the total contribution of the covariance effect will be approximately zero. That is, if the intercept of the marginal social objective tends to be high when the intercept of the marginal private objective in sector 1 is high and at the same time the intercept of the marginal private objective in sector 2 is low, then the private agent behaves in one sector according to the will of the regulator and in opposition to the regulator in the other sector. Overall, these two opposing forces cancel out in this case. This result stresses that one has to look at all affected sectors and should not draw premature conclusions based on observations about one sector only.

The *total effect* is again the sum of these three effects. Compared to the single good case, the price regulation has more room to be advantageous because it can, under some circumstances, exploits the statistical relationship between different sectors. However, even for the special case of atmospheric externalities, it is not ex ante clear that a uniform price or a total quantity regulation is superior. In particular it is not clear that a unified certificate market is better than sector-specific CO2-taxes.

For the general case stated in the proposition the same qualifications as for the single good case apply: All three effects have to be corrected for additional covariance, coskewness and other ambiguous terms. However, the general logic is the same as for the single good case.

3.5 Discussion and Concluding Remarks

This section discusses matters of microfoundations with many private agents. Conveniently, matters of implementation and decentralization come up naturally when introducing multiple private agents. In addition the relation of the approach in this paper to principal agent and mechanism design models are discussed.

Microfoundation The main text assumes that the regulator influences the actions of a single private agent. This was assumed for expositional simplicity only. Assume now that there are $n > 1$ private agents. Denote the quantities chosen by private agent $i = 1, ..., n$ by x^i and their private objective by $S^i(x^i, z)$. The following analysis applies to non-optimal regulations as well as optimal regulations.

For the *single good price regulation* the regulator specifies a price p and private agents choose x^i to maximize

$$S^i(x^i, z) - px^i.$$

The quantities $x^1, \ldots, x^n$ the private agent choose are exactly the same a representative private agent with maximization problem

$$\sum_{i=1}^{n} S^i(x^i, z) - p \sum_{i=1}^{n} x^i$$

would choose, namely those satisfying the first order conditions

$$\nabla_x S^i(x^i, z) = \nabla_x S^j(x^j, z) \quad (= p)$$

for all $i, j = 1, \dots n$. Of course, the total quantity is then also the same in both environments.

For the *single good quantity regulation* the regulator specifies an inelastic total supply of certificates $\bar{x}$ and the private agents have to buy certificates at market price p for each unit of the good they produce or consume. This provides a way to implement quantity regulations in a decentralized way. The private agents again choose x^i to maximize

$$S^i(x^i, z) - px^i.$$

With the same reasoning as for the single good price regulation, the assignment of individual quantities to private agents will be the same as the one a representative private agent would choose. The market clearing condition, i.e., the condition that the total demand for certificates determined by the first order conditions equals the inelastic supply of certificates $\bar{x}$ guarantees that the total quantity is the same with a certificate market for many private agents and a representative private agent.

For the *single good quadratic regulation* the regulator specifies an (inverse) total supply of certificates $R'(x) = r_1 + 2r_2x$ and the private agents have to buy certificates at market price p, as for the single good quantity regulation. Again, the assignment of individual quantities to private agents is the same a representative private agent would choose. The market clearing condition guarantees that the resulting allocation is the same a representative private agent with the following maximization problem would choose:

$$\sum_{i=1}^{n} S^i(x^i, z) - R\left(\sum_{i=1}^{n} x^i\right).$$

Note that with this mechanism other non-linear regulations can be implemented in a decentralized way as well. The single good price and quantity regulation are the extreme cases of a perfectly elastic or inelastic supply of certificates.

For the *multiple good price regulation* the regulator specifies a price vector p and the private agents choose x^i to maximize

$$S^i(x^i, z) - (x^i)^T p = s_0 + s^i_{1[1]}x^i_1 + s^i_{1[2]}x^i_2 + s^i_{2[11]}(x^i_1)^2 + s^i_{2[22]}(x^i_2)^2 - p_1x^i_1 - p_2x^i_2.$$

The quantities $x^1, \dots, x^n$ the private agents choose are exactly the same a representative private agent with maximization problem

$$\sum_{i=1}^{n} S^i(x^i, z) - \sum_{i=1}^{n} (x^i)^T p$$

would choose, namely those satisfying the first order conditions

$$\nabla_x S^i(x^i, z) = \nabla_x S^j(x^j, z) \quad (= p)$$

for all $i, j = 1, \dots n$. The problem is here particularly simple because $\partial^2 S^i(x^i, z)/(\partial x_1^i \partial x_2^i) = 0$. Of course, the total quantities are then also the same in both environments.

For the *multiple good quantity regulation* the regulator specifies a vector of inelastic total supplies of certificates $\bar{x}$ (the regulator sets up one certificate market per sector) and the private agents have to buy certificates at market prices p. With the same reasoning as before the assignment of individual quantities to private agents will be the same as the one a representative private agent would choose and market clearing guarantees that the total quantities in each sector will coincide as well.

For the *multiple good total quantity regulation* the regulator specifies an inelastic total supply of certificates $\bar{X}$ and the private agents have to buy certificates at market price p for each unit of any good they produce or consume. Note that the total quantity $\bar{X}$ refers here to the sum of all quantities in all sectors (and is therefore a scalar) and that p is a single price (and therefore a scalar as well). Adjusting the formulas from before shows that private agent $i = 1, \dots, n$ chooses x^i to maximize

$$S^i(x^i, z) - p(x_1^i + x_2^i)$$

and that the representative private agent chooses $x^1, \dots, x^n$ to maximize

$$\sum_{i=1}^{n} S^i(x^i, z) - p \sum_{i=1}^{n} x_1^i + x_2^i.$$

For the same reasons as before the assignment of individual quantities to private agents will be the same as the one a representative private agent would choose and market clearing guarantees that the total quantity will be the same as well.

For the *multiple good quadratic regulation* the regulator specifies (inverse) total supplies of certificates $\nabla_x R(x) = r_1 + 2r_2 x$ (the regulator sets up one certificate market per sector) and the private agents have to buy certificates at market prices p. Note that $\nabla_x R(x)$ is a vector and that the inverse supply is a function from $\mathbb{R}_+^2$ to $\mathbb{R}_+^2$ for two goods. Again, this mechanism can be used to implement other non-linear regulations as well. Although the multiple goods case looks more complicated, the same basic arguments imply that the allocation of goods to private agent is the same a representative private agent would choose. Again, market clearing leads to the same total quantity in both cases

Mechanism Design Ideally, in analyzing optimal regulations one would want to impose only the weakest assumptions on i) the stochastic structure and ii) the admissible regulations.[13] As the characterization of optimal regulations in full generality is an unsolved problem, the literature pursues two routes: The route followed in this paper imposes no restriction on the form of uncertainty, but characterizes optimal regulations only within certain classes of regulations (price regulations, quantity regulations, etc.). On the other hand, the mechanism design literature is fully general with respect to the admissible regulations, but imposes strong assumptions on the stochastic structure (Spence (1974)-Mirrlees (1971)-type single-crossing conditions, etc.). This is especially true for the multidimensional case, pioneered by Rochet (1987); Armstrong (1996); Rochet and Choné (1998). Because in this paper no assumptions on the structure of uncertainty are made, it is without loss of generality to assume that z is a scalar random variable; in general, however, one should think of z as a vector-valued random variable. Basov (2006) discusses the additional complications that arise when one extends the unidimensional analysis to the multidimensional case. For example, in his Theorem 179, he shows that under the generalized single-crossing property,

$$\nabla_z S(z,x) = \nabla_z S(z,x') \quad \Rightarrow \quad x = x',$$

an allocation $x(z)$ is incentive compatible if and only if $\hat{S}(z) := S(z,x(z)) - R(x(z))$ is S-convex (the multidimensional analogue of monotonicity in the unidimensional case).[14] In that case implementable allocations satisfy the envelope condition $\nabla_z \hat{S}(z) = \nabla_z S(z,x(z))$ and optimal allocations can be characterized via the usual optimal control techniques. The increased complexity stems from the fact that a priori it is unclear in which direction the local incentive compatibility constraints will be binding. A more specialized literature on income taxation expands upon the seminal contribution by Saez (2001) and uses tax perturbation methods to characterize optimal taxes, see e.g., Golosov et al. (2014b); Sachs et al. (2020); Bierbrauer et al. (2017) or Jacquet and Lehmann (2020). Again, the methods employed in these papers rely on single-crossing properties of preferences. The approach followed in this paper should therefore be seen as complementary to the mechanism design literature.

As a final remark on the multiple private agent case and mechanism design, note that if one allows for complicated regulations that can condition on the cross-section distribution of idiosyncratic uncertainty regarding the private objective, then the regulator might be able to implement first best. E.g., Piketty (1993) shows that under a single-crossing condition a social planer can implement any first-best allocation via generalized tax func-

[13]If one values the simplicity of regulations in itself, then one might want to restrict the class of admissible regulations regulations to simple regulations, even if this comes at a welfare loss. This would be an argument in favor of the approach followed in this paper.

[14]A function $\hat{S}(z)$ is $S(z,x)$-convex if there exists a function $R(x)$ such that $\hat{S}(z) = \sup_x S(z,x) - R(x)$

tions (that condition on the cross-section of skills) and Crémer and McLean (1985, 1988) demonstrate that if the beliefs of the private agents about preferences are correlated an auctioneer can extract the full surplus when running an auction (again, by constructing an auction that conditions on the cross-section distribution of beliefs). However, these results are less relevant for this paper as the main interpretation of the variable z is uncertainty and not private information; that is, the regulator knows from which distribution z is drawn (or, at least, the regulator can give an informed guess about some moments of this distribution), but knowing $n-1$ realized values of z does not allow the regulator to infer the nth value of z.

Conclusion This paper develops a flexible framework to study the regulation of (multiple) externalities under uncertainty. For the single good case a novel decomposition of Weitzman (1974)'s coefficient of comparative advantage into a quantity effect, a variance effect and a covariance effect is derived; these effects are also important for the characterization of the optimal quadratic regulation. For the multiple good case it was shown that the welfare differences between various regulations can also be explained in terms of these three effects. In particular, for atmospheric externalities and compared to a single good case, to judge whether a tax is superior to a unified cross-sectoral certificate market, the inter-sectoral covariances play an important role.

3.A Appendix

Throughout the appendix, the following identity for random variales $z_1, \ldots, z_n$ from Brown and Alexander (1991) is helpful:

$$\frac{\mathbb{E}[z_1 \cdots z_n]}{\mathbb{E}[z_1] \cdots \mathbb{E}[z_n]} = 1 + \sum_{k=1}^{n} \sum_{\substack{\text{all } k\text{-tuples} \\ \{i_1,\ldots,i_k\} \subset \{1,\ldots,n\}}} \frac{C[z_{i_1}, \ldots, z_{i_k}]}{\mathbb{E}[z_{i_1}] \cdots \mathbb{E}[z_{i_k}]}.$$

This can easily be proven by induction. For example, for $n = 2, 3, 4$, we have

$$\begin{aligned}
\frac{\mathbb{E}[z_1 z_2]}{\mathbb{E}[z_1]\mathbb{E}[z_2]} &= 1 + \frac{C[z_1, z_2]}{\mathbb{E}[z_1]\mathbb{E}[z_2]}, \\
\frac{\mathbb{E}[z_1 z_2 z_3]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_3]} &= 1 + \frac{C[z_1, z_2]}{\mathbb{E}[z_1]\mathbb{E}[z_2]} + \frac{C[z_1, z_3]}{\mathbb{E}[z_1]\mathbb{E}[z_3]} + \frac{C[z_2, z_3]}{\mathbb{E}[z_2]\mathbb{E}[z_3]} + \frac{C[z_1, z_2, z_3]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_3]}, \\
\frac{\mathbb{E}[z_1 z_2 z_3 z_4]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_3]\mathbb{E}[z_4]} &= 1 + \frac{C[z_1, z_2]}{\mathbb{E}[z_1]\mathbb{E}[z_2]} + \frac{C[z_1, z_3]}{\mathbb{E}[z_1]\mathbb{E}[z_3]} + \frac{C[z_1, z_4]}{\mathbb{E}[z_1]\mathbb{E}[z_4]} + \frac{C[z_2, z_3]}{\mathbb{E}[z_2]\mathbb{E}[z_3]} \\
&\quad + \frac{C[z_2, z_4]}{\mathbb{E}[z_2]\mathbb{E}[z_4]} + \frac{C[z_3, z_4]}{\mathbb{E}[z_3]\mathbb{E}[z_4]} + \frac{C[z_1, z_2, z_3]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_3]} + \frac{C[z_1, z_2, z_4]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_4]} \\
&\quad + \frac{C[z_1, z_3, z_4]}{\mathbb{E}[z_1]\mathbb{E}[z_3]\mathbb{E}[z_4]} + \frac{C[z_2, z_3, z_4]}{\mathbb{E}[z_2]\mathbb{E}[z_3]\mathbb{E}[z_4]} + \frac{C[z_1, z_2, z_3, z_4]}{\mathbb{E}[z_1]\mathbb{E}[z_2]\mathbb{E}[z_3]\mathbb{E}[z_4]}.
\end{aligned}$$

Proof of Lemma 4: Assuming the validity of FOCs, IC can be written as

$$x(p, z) = \frac{1}{2} s_2(z)^{-1}(p - s_1(z)).$$

Because the price regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal price regulation is given by

$$p^* \in \arg\max_p \mathbb{E}\left[W\left(x(p, z), z\right) + \lambda S\left(x(p, z), z\right)\right].$$

The maximization problem can be written as

$$\max_p \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_1 \frac{1}{2} s_2^{-1}(p - s_1) + \tilde{w}_2 \frac{1}{4} s_2^{-2}(p - s_1)^2\right].$$

The FOC w.r.t. p is given by

$$0 = \mathbb{E}\left[\tilde{w}_1 s_2^{-1} + \tilde{w}_2 s_2^{-2}(p - s_1)\right].$$

Solving for p yields

$$p^* = \frac{\mathbb{E}\left[\tilde{w}_2 s_1 s_2^{-2}\right] - \mathbb{E}\left[\tilde{w}_1 s_2^{-1}\right]}{\mathbb{E}\left[\tilde{w}_2 s_2^{-2}\right]}.$$

Proof of Lemma 5: Because the quantity regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quantity regulation is given by

$$\bar{x}^* \in \arg\max_{\bar{x}} \mathbb{E}\left[W\left(\bar{x}, z\right) + \lambda S\left(\bar{x}, z\right)\right].$$

The maximization problem can be written as

$$\max_{\bar{x}} \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_1\bar{x} + \tilde{w}_2\bar{x}^2\right].$$

The FOC w.r.t. $\bar{x}$ is given by

$$0 = \mathbb{E}\left[\tilde{w}_1 + 2\tilde{w}_2\bar{x}\right].$$

Solving for $\bar{x}$ yields

$$\bar{x}^* = -\frac{\mathbb{E}[\tilde{w}_1]}{2\mathbb{E}[\tilde{w}_2]}.$$

Proof of Lemma 6: Assuming the validity of FOCs, IC can be written as

$$x(r_1, r_2, z) = -\frac{1}{2}(r_2 - s_2(z))^{-1}(r_1 - s_1(z)).$$

Because the quadratic regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quadratic regulation is given by

$$(r_1^*, r_2^*) \in \arg\max_{r_1, r_2} \mathbb{E}\left[W\left(x(r_1, r_2, z), z\right) + \lambda S\left(x(r_1, r_2, z), z\right)\right].$$

The maximization problem can be written as

$$\max_{r_1, r_2} \mathbb{E}\left[\tilde{w}_0 - \tilde{w}_1\frac{1}{2}(r_2 - s_2)^{-1}(r_1 - s_1) + \tilde{w}_2\frac{1}{4}(r_2 - s_2)^{-2}(r_1 - s_1)^2\right].$$

The FOCs w.r.t. r_1, r_2 are given by

$$\begin{aligned}
0 &= -\mathbb{E}[\tilde{w}_1(r_2 - s_2)^{-1}] + r_1\mathbb{E}[\tilde{w}_2(r_2 - s_2)^{-2}] - \mathbb{E}[\tilde{w}_2 s_1(r_2 - s_2)^{-2}], \\
0 &= \mathbb{E}[\tilde{w}_1(r_2 - s_2)^{-2}(r_1 - s_1)] - \mathbb{E}[\tilde{w}_2(r_2 - s_2)^{-3}(r_1 - s_1)^2].
\end{aligned}$$

Assuming that s_2 is deterministic, one can solve for r_1^*, r_2^*

$$\begin{aligned}
r_1^* &= \frac{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1^2] - \mathbb{E}[\tilde{w}_1 s_1]\mathbb{E}[\tilde{w}_2 s_1]}{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1] - \mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_1 s_1]}, \\
r_2^* &= s_2 + \frac{\mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_2 s_1^2] - \mathbb{E}[\tilde{w}_2 s_1]^2}{\mathbb{E}[\tilde{w}_1]\mathbb{E}[\tilde{w}_2 s_1] - \mathbb{E}[\tilde{w}_2]\mathbb{E}[\tilde{w}_1 s_1]}.
\end{aligned}$$

Proof of Proposition 2: Plugging p^* into the welfare function yields

$$\begin{aligned}
E\tilde{W}^p &:= \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_1 \frac{1}{2} s_2^{-1}(p^* - s_1) + \tilde{w}_2 \frac{1}{4} s_2^{-2}(p^* - s_1)^2\right] \\
&= \mathbb{E}[\tilde{w}_0] - \frac{1}{2}\mathbb{E}[\tilde{w}_1 s_1 s_2^{-1}] + \frac{1}{4}\mathbb{E}[\tilde{w}_2 s_1^2 s_2^{-2}] - \frac{\left(\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}] - \mathbb{E}[\tilde{w}_1 s_2^{-1}]\right)^2}{4\mathbb{E}[\tilde{w}_2 s_2^{-2}]} \\
&= \text{ quantity effect } + \text{ variance effect } + \text{ covariance effect}
\end{aligned}$$

where

$$\begin{aligned}
\text{quantity effect } &:= \mathbb{E}[\tilde{w}_0] - \frac{\mathbb{E}[\tilde{w}_1 s_2^{-1}]^2}{4\mathbb{E}[\tilde{w}_2 s_2^{-2}]}, \\
\text{variance effect } &:= \frac{1}{4}\left(\mathbb{E}[\tilde{w}_2 s_1^2 s_2^{-2}] - \frac{\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}]^2}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}\right), \\
\text{covariance effect } &:= -\frac{1}{2}\left(\mathbb{E}[\tilde{w}_1 s_1 s_2^{-1}] - \frac{\mathbb{E}[\tilde{w}_1 s_2^{-1}]\mathbb{E}[\tilde{w}_2 s_1 s_2^{-2}]}{\mathbb{E}[\tilde{w}_2 s_2^{-2}]}\right).
\end{aligned}$$

Similarly, plugging $\bar{x}$ into the welfare function yields

$$E\tilde{W}^{\bar{x}} := \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_1 \bar{x}^* + \tilde{w}_2 \bar{x}^{*2}\right] = \text{ quantity effect } := \mathbb{E}[\tilde{w}_0] - \frac{\mathbb{E}[\tilde{w}_1]^2}{4\mathbb{E}[\tilde{w}_2]}.$$

Calculating the welfare difference yields the result.

Proof of Lemma 7: For future reference define

$$\Omega := \mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}\right]\mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}\right] - \mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]} s_{2[22]}}\right]^2.$$

For the proof it is more convenient to work with matrix notation. The first formula is also valid for s_2 non-diagonal and $n > 2$ goods. Assuming the validity of FOCs, IC can be written as

$$x(p, z) = \frac{1}{2} s_2(z)^{-1}(p - s_1(z)).$$

Because the price regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal price regulation is given by

$$p^* \in \arg\max_p \mathbb{E}\left[W\left(x(p, z), z\right) + \lambda S\left(x(p, z), z\right)\right].$$

The maximization problem can be written as

$$\max_p \mathbb{E}\left[\tilde{w}_0 + \frac{1}{2}(p-s_1)^T s_2^{-1}\tilde{w}_1 + \frac{1}{4}(p-s_1)^T s_2^{-1}\tilde{w}_2 s_2^{-1}(p-s_1)\right].$$

The FOC w.r.t. p is given by

$$0 = \mathbb{E}\left[s_2^{-1}\tilde{w}_1 + s_2^{-1}\tilde{w}_2 s_2^{-1}(p-s_1)\right].$$

Solving for p yields

$$\begin{aligned}p^* &= \mathbb{E}\left[s_2^{-1}\tilde{w}_2 s_2^{-1}\right]^{-1}\left(\mathbb{E}\left[s_2^{-1}\tilde{w}_2 s_2^{-1}s_1\right] - \mathbb{E}\left[s_2^{-1}\tilde{w}_1\right]\right)\\ &= \frac{1}{\Omega}\begin{pmatrix} \mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right] - \mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right] \\ -\mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right] + \mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}\right]\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}} - \frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]\end{pmatrix}.\end{aligned}$$

where the second equality uses that s_2 is diagonal.

Proof of Lemma 8: Assuming the validity of FOCs, IC can be written as

$$x_k(p_0, z) = \frac{p_0 - s_{1[k]}(z)}{2s_{2[kk]}(z)}, \quad k = 1, 2.$$

The maximization problem can be written as

$$\begin{aligned}&\max_{p_0}\mathbb{E}\left[\tilde{w}_0 + \tilde{w}_{1[1]}\left(\frac{p_0 - s_{1[1]}}{2s_{2[11]}}\right) + \tilde{w}_{1[2]}\left(\frac{p_0 - s_{1[2]}}{2s_{2[22]}}\right)\right]\\ &\quad + \mathbb{E}\left[\tilde{w}_{2[11]}\left(\frac{p_0 - s_{1[1]}}{2s_{2[11]}}\right)^2 + \tilde{w}_{2[22]}\left(\frac{p_0 - s_{1[2]}}{2s_{2[22]}}\right)^2 + 2\tilde{w}_{2[12]}\left(\frac{p_0 - s_{1[1]}}{2s_{2[11]}}\right)\left(\frac{p_0 - s_{1[2]}}{2s_{2[22]}}\right)\right].\end{aligned}$$

The FOC w.r.t. p_0 is given by

$$\begin{aligned}0 = &\,\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}} - \frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} - \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} - \frac{(s_{1[1]} + s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\\ &+ p_0\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right].\end{aligned}$$

Solving for p_0 yields

$$p_0^* = -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}} - \frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} - \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} - \frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}{\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}.$$

Proof of Lemma 9: For the proof it is more convenient to work with matrix notation. The first formula is also valid for s_2 non-diagonal and $n > 2$ goods. Because the quantity regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quantity regulation is given by

$$\bar{x}^* \in \arg\max_{\bar{x}} \mathbb{E}\left[W\left(\bar{x}, z\right) + \lambda S\left(\bar{x}, z\right)\right].$$

The maximization problem can be written as

$$\max_{\bar{x}} \mathbb{E}\left[\tilde{w}_0 + \bar{x}^T \tilde{w}_1 + \bar{x}^T \tilde{w}_2 \bar{x}\right].$$

The FOC w.r.t. $\bar{x}$ is given by

$$0 = \mathbb{E}\left[\tilde{w}_1\right] + 2\mathbb{E}\left[\tilde{w}_2\right]\bar{x}.$$

Solving for $\bar{x}$ yields

$$\begin{aligned}
\bar{x}^* &= -\frac{1}{2}\mathbb{E}\left[\tilde{w}_2\right]^{-1}\mathbb{E}\left[\tilde{w}_1\right] \\
&= -\frac{1}{2}\frac{1}{\mathbb{E}[\tilde{w}_{2[11]}]\mathbb{E}[\tilde{w}_{2[22]}] - \mathbb{E}[\tilde{w}_{2[12]}]^2}\begin{pmatrix}\mathbb{E}[\tilde{w}_{1[1]}]\mathbb{E}[\tilde{w}_{2[22]}] - \mathbb{E}[\tilde{w}_{1[2]}]\mathbb{E}[\tilde{w}_{2[12]}] \\ \mathbb{E}[\tilde{w}_{1[2]}]\mathbb{E}[\tilde{w}_{2[11]}] - \mathbb{E}[\tilde{w}_{1[1]}]\mathbb{E}[\tilde{w}_{2[12]}]\end{pmatrix}.
\end{aligned}$$

Proof of Lemma 10: Because the quantity regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quantity regulation is given by

$$\bar{x}_0^* \in \arg\max_{\bar{x}_0} \mathbb{E}\left[W\left(\bar{x}_0, z\right) + \lambda S\left(\bar{x}_0, z\right)\right].$$

The maximization problem can be written as

$$\max_{\bar{x}_0} \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_{1[1]}\bar{x}_0 + \tilde{w}_{1[2]}\bar{x}_0 + \tilde{w}_{2[11]}\bar{x}_0^2 + \tilde{w}_{2[22]}\bar{x}_0^2 + 2\tilde{w}_{2[12]}\bar{x}_0^2\right].$$

The FOC w.r.t. $\bar{x}_0$ is given by

$$0 = \mathbb{E}\left[\tilde{w}_{1[1]} + \tilde{w}_{1[2]}\right] + 2\mathbb{E}\left[\tilde{w}_{2[11]} + \tilde{w}_{2[22]} + 2\tilde{w}_{2[12]}\right]\bar{x}_0.$$

Solving for $\bar{x}_0$ yields

$$\bar{x}_0^* = -\frac{\mathbb{E}[\tilde{w}_{1[1]} + \tilde{w}_{1[2]}]}{2\mathbb{E}[\tilde{w}_{2[11]} + \tilde{w}_{2[22]} + 2\tilde{w}_{2[12]}]}.$$

Proof of Lemma 11: Assuming the validity of FOCs, IC can be written as

$$x_k(\bar{X}, z) = \frac{s_{1[3-k]} - s_{1[k]} + 2s_{2[3-k,3-k]}\bar{X}}{2s_{2[11]} + 2s_{2[22]}}, \quad k = 1, 2.$$

Because the total quantity regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quantity regulation is given by

$$\bar{X}^* \in \arg\max_{\bar{X}} \mathbb{E}\left[W\left(\bar{X}, z\right) + \lambda S\left(\bar{x}, z\right)\right].$$

The maximization problem can be written as

$$\begin{aligned}
&\max_{\bar{X}} \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_{1[1]}x_1(\bar{X}, z) + \tilde{w}_{1[2]}x_2(\bar{X}, z)\right] \\
&\quad + \mathbb{E}\left[\tilde{w}_{2[11]}x_1(\bar{X}, z)^2 + \tilde{w}_{2[22]}x_2(\bar{X}, z)^2 + 2\tilde{w}_{2[12]}x_1(\bar{X}, z)x_2(\bar{X}, z)\right].
\end{aligned}$$

The FOC w.r.t. $\bar{X}$ is given by

$$\begin{aligned}
0 = \mathbb{E}&\left[\frac{\tilde{w}_{1[1]}s_{2[22]} + \tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]} + s_{2[22]}} + \frac{\left(\tilde{w}_{2[11]}s_{2[22]} + \tilde{w}_{2[12]}s_{2[11]} - \tilde{w}_{2[22]}s_{2[11]} - \tilde{w}_{2[12]}s_{2[22]}\right)\left(s_{1[2]} - s_{1[1]}\right)}{\left(s_{2[11]} + s_{2[22]}\right)^2}\right] \\
&+ 2\bar{X}\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2 + \tilde{w}_{2[22]}s_{2[11]}^2 + 2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{\left(s_{2[11]} + s_{2[22]}\right)^2}\right].
\end{aligned}$$

Solving for $\bar{X}$ yields

$$\bar{X}^* = -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]} + \tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]} + s_{2[22]}} + \frac{(\tilde{w}_{2[11]}s_{2[22]} + \tilde{w}_{2[12]}s_{2[11]} - \tilde{w}_{2[22]}s_{2[11]} - \tilde{w}_{2[12]}s_{2[22]})(s_{1[2]} - s_{1[1]})}{(s_{2[11]} + s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2 + \tilde{w}_{2[22]}s_{2[11]}^2 + 2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]} + s_{2[22]})^2}\right]}.$$

Proof of Lemma 12: For the subsequent proof the following two formulas are useful (lowercase letters denote column vectors and uppercase letters matrices):

$$\begin{aligned}
\frac{\partial a^T(X-A)^{-1}b}{\partial X} &= -(X-A)^{-T}ab^T(X-A)^{-T}, \\
\frac{\partial a^T(X-A)^{-T}B(X-A)^{-1}b}{\partial X} &= -(X-A)^{-T}(B(X-A)^{-1}ba^T + B^T(X-A)^{-1}ab^T)(X-A)^{-T}.
\end{aligned}$$

Assuming the validity of FOCs, IC can be written as

$$x(r_1, r_2, z) = -\frac{1}{2}(r_2 - s_2(z))^{-1}(r_1 - s_1(z)).$$

Because the quadratic regulation includes a lump-sum payment or transfer, PC will always be binding and the optimal quadratic regulation is given by

$$(r_1^*, r_2^*) \in \arg\max_{r_1,r_2} \mathbb{E}\left[W\left(x(r_1,r_2,z),z\right) + \lambda S\left(x(r_1,r_2,z),z\right)\right].$$

The maximization problem can be written as

$$\max_{r_1,r_2} \mathbb{E}\left[\tilde{w}_0 - \frac{1}{2}\tilde{w}_1(r_1-s_1)^T(r_2-s_2)^{-1} + \frac{1}{4}(r_1-s_1)^T(r_2-s_2)^{-1}\tilde{w}_2(r_2-s_2)^{-1}(r_1-s_1)\right].$$

The FOCs w.r.t. r_1, r_2 are given by

$$\begin{aligned}
&\mathbb{E}\left[(r_2-s_2)^{-1}w_1\right] \\
=&\mathbb{E}\left[(r_2-s_2)^{-1}w_2(r_2-s_2)^{-1}(r_1-s_1)\right], \\
&\mathbb{E}\left[(r_2-s_2)^{-1}(r_1-s_1)w_1^T(r_2-s_2)^{-1}\right] \\
=&\mathbb{E}\left[(r_2-s_2)^{-1}\left(w_2(r_2-s_2)^{-1}(r_1-s_1)(r_1-s_1)^T\right)(r_2-s_2)^{-1}\right].
\end{aligned}$$

Proof of the remaining propositions: For the calculation of the various coefficients of comparative advantage, it is helpful to calculate the welfare under the various regulations first. The coefficients are then simply given by the welfare differences.

Plugging p^* into the welfare function yields

$$\begin{aligned}
E\tilde{W}^p &:= \mathbb{E}\left[\tilde{w}_0 + \frac{1}{2}(p^*-s_1)^T s_2^{-1}\tilde{w}_1 + \frac{1}{4}(p^*-s_1)^T s_2^{-1}\tilde{w}_2 s_2^{-1}(p^*-s_1)\right] \\
&= \text{ quantity effect } + \text{ variance effect } + \text{ covariance effect}
\end{aligned}$$

where

$$\begin{aligned}
\text{quantity effect } &:= \mathbb{E}[\tilde{w}_0] - \frac{1}{4}\mathbb{E}[\tilde{w}_1^T s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1], \\
\text{variance effect } &:= \frac{1}{4}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}s_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}s_1]\right), \\
\text{covariance effect } &:= -\frac{1}{2}\left(\mathbb{E}[s_1^T s_2^{-1}\tilde{w}_1] - \mathbb{E}[s_1^T s_2^{-1}\tilde{w}_2 s_2^{-1}]\mathbb{E}[s_2^{-1}\tilde{w}_2 s_2^{-1}]^{-1}\mathbb{E}[s_2^{-1}\tilde{w}_1]\right).
\end{aligned}$$

For s_2 diagonal these three effects simplify to

$$\begin{aligned}
\text{QE} &= \mathbb{E}[\tilde{w}_0] - \frac{1}{4\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right]^2 - \frac{1}{4\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]^2 \\
&\quad + \frac{1}{2\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right], \\
\text{VE} &= \frac{1}{4}\mathbb{E}\left[\frac{s_{1[1]}^2\tilde{w}_{2[11]}}{s_{2[11]}^2}\right] + \frac{1}{4}\mathbb{E}\left[\frac{s_{1[2]}^2\tilde{w}_{2[22]}}{s_{2[22]}^2}\right] + \frac{1}{2}\mathbb{E}\left[\frac{s_{1[1]}s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right] \\
&\quad - \frac{1}{4\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]^2 - \frac{1}{4\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}\right]\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]^2 \\
&\quad + \frac{1}{2\Omega}\mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right], \\
\text{CE} &= -\frac{1}{2}\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{s_{1[2]}\tilde{w}_{1[2]}}{s_{2[22]}}\right] \\
&\quad + \frac{1}{2\Omega}\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{s_{1[2]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\left(\mathbb{E}\left[\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right] - \mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]\right) \\
&\quad + \frac{1}{2\Omega}\mathbb{E}\left[\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} + \frac{s_{1[1]}\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\left(\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right] - \mathbb{E}\left[\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}\right]\right).
\end{aligned}$$

Plugging $\bar{x}^*$ into the welfare function yields

$$\begin{aligned}
E\tilde{W}^{\bar{x}} &:= \mathbb{E}\left[\tilde{w}_0 + \bar{x}^T\tilde{w}_1 + \bar{x}^T\tilde{w}_2\bar{x}\right] \\
&= \mathbb{E}[\tilde{w}_0] - \frac{1}{4}\mathbb{E}[\tilde{w}_1]^T\mathbb{E}[\tilde{w}_2]^{-1}\mathbb{E}[\tilde{w}_1] \\
&= \mathbb{E}[\tilde{w}_0] - \frac{1}{4}\frac{\mathbb{E}[\tilde{w}_{1[1]}]^2\mathbb{E}[\tilde{w}_{2[22]}] + \mathbb{E}[\tilde{w}_{1[2]}]^2\mathbb{E}[\tilde{w}_{2[11]}] - 2\mathbb{E}[\tilde{w}_{1[1]}]\mathbb{E}[\tilde{w}_{1[2]}]\mathbb{E}[\tilde{w}_{2[12]}]}{\mathbb{E}[\tilde{w}_{2[11]}]\mathbb{E}[\tilde{w}_{2[22]}] - \mathbb{E}[\tilde{w}_{2[12]}]^2}.
\end{aligned}$$

Plugging p_0^* into the welfare function yields

$$\begin{aligned}
E\tilde{W}^{p_0} &:= \mathbb{E}\left[\tilde{w}_0 + \tilde{w}_{1[1]}\left(\frac{p_0^* - s_{1[1]}}{2s_{2[11]}}\right) + \tilde{w}_{1[2]}\left(\frac{p_0^* - s_{1[2]}}{2s_{2[22]}}\right)\right] \\
&\quad + \mathbb{E}\left[\tilde{w}_{2[11]}\left(\frac{p_0^* - s_{1[1]}}{2s_{2[11]}}\right)^2 + \tilde{w}_{2[22]}\left(\frac{p_0^* - s_{1[2]}}{2s_{2[22]}}\right)^2 + 2\tilde{w}_{2[12]}\left(\frac{p_0^* - s_{1[1]}}{2s_{2[11]}}\right)\left(\frac{p_0^* - s_{1[2]}}{2s_{2[22]}}\right)\right] \\
&= \mathbb{E}\left[\tilde{w}_0 - \frac{\tilde{w}_{1[1]}s_{1[1]}}{2s_{2[11]}} - \frac{\tilde{w}_{1[2]}s_{1[2]}}{2s_{2[22]}} + \frac{\tilde{w}_{2[11]}s_{1[1]}^2}{4s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}s_{1[2]}^2}{4s_{2[22]}^2} + \frac{\tilde{w}_{2[12]}s_{1[1]}s_{1[2]}}{2s_{2[11]}s_{2[22]}}\right] \\
&\quad - \frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}} + \frac{\tilde{w}_{1[2]}}{s_{2[22]}} - \frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2} - \frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2} - \frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2} + \frac{\tilde{w}_{2[22]}}{s_{2[22]}^2} + 2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]} \\
&= \text{ quantity effect } + \text{ variance effect } + \text{ covariance effect}
\end{aligned}$$

where

$$
\begin{aligned}
\text{quantity effect } &:= -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}+\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}+\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}+2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]},\\
\text{variance effect } &:= \frac{1}{4}\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{1[1]}^2}{s_{2[11]}^2}+\frac{\tilde{w}_{2[22]}s_{1[2]}^2}{s_{2[22]}^2}+2\frac{\tilde{w}_{2[12]}s_{1[1]}s_{1[2]}}{s_{2[11]}s_{2[22]}}\right]\\
&\quad-\frac{\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2}+\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2}+\frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}+\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}+2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]},\\
\text{covariance effect } &:= -\frac{1}{2}\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{1[1]}}{s_{2[11]}}+\frac{\tilde{w}_{1[2]}s_{1[2]}}{s_{2[22]}}\right]\\
&\quad+\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}}{s_{2[11]}}+\frac{\tilde{w}_{1[2]}}{s_{2[22]}}\right]\mathbb{E}\left[\frac{s_{1[1]}\tilde{w}_{2[11]}}{s_{2[11]}^2}+\frac{s_{1[2]}\tilde{w}_{2[22]}}{s_{2[22]}^2}+\frac{(s_{1[1]}+s_{1[2]})\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}}{s_{2[11]}^2}+\frac{\tilde{w}_{2[22]}}{s_{2[22]}^2}+2\frac{\tilde{w}_{2[12]}}{s_{2[11]}s_{2[22]}}\right]}.
\end{aligned}
$$

Plugging $\bar{x}_0^*$ into the welfare function yields

$$
\begin{aligned}
E\tilde{W}^{\bar{x}_0} &:= \mathbb{E}\left[\tilde{w}_0+\tilde{w}_{1[1]}\bar{x}_0+\tilde{w}_{1[2]}\bar{x}_0+\tilde{w}_{2[11]}\bar{x}_0^2+\tilde{w}_{2[22]}\bar{x}_0^2+2\tilde{w}_{2[12]}\bar{x}_0^2\right]\\
&= \mathbb{E}[\tilde{w}_0]-\frac{\mathbb{E}[\tilde{w}_{1[1]}+\tilde{w}_{1[2]}]^2}{4\mathbb{E}[\tilde{w}_{2[11]}+\tilde{w}_{2[22]}+2\tilde{w}_{2[12]}]}.
\end{aligned}
$$

Plugging $\bar{X}^*$ into the welfare function yields

$$
\begin{aligned}
E\tilde{W}^{\bar{X}} &:= \mathbb{E}\left[\tilde{w}_0+\tilde{w}_{1[1]}x_1(\bar{X},z)+\tilde{w}_{1[2]}x_2(\bar{X},z)\right]\\
&\quad+\mathbb{E}\left[\tilde{w}_{2[11]}x_1(\bar{X},z)^2+\tilde{w}_{2[22]}x_2(\bar{X},z)^2+2\tilde{w}_{2[12]}x_1(\bar{X},z)x_2(\bar{X},z)\right]\\
&= \mathbb{E}\left[\tilde{w}_0+\frac{(\tilde{w}_{1[1]}-\tilde{w}_{1[2]})(s_{1[2]}-s_{1[1]})}{2(s_{2[11]}+s_{2[22]})}+\frac{(\tilde{w}_{2[11]}+\tilde{w}_{2[22]}-2\tilde{w}_{2[12]})(s_{1[2]}-s_{1[1]})^2}{2(s_{2[11]}+s_{2[22]})^2}\right]\\
&\quad-\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}+\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}\\
&= \text{ quantity effect } + \text{ variance effect } + \text{ covariance effect}
\end{aligned}
$$

where

$$
\begin{aligned}
\text{quantity effect} &:= -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}, \\
\text{variance effect} &:= \frac{1}{4}\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}+\tilde{w}_{2[22]}-2\tilde{w}_{2[12]})(s_{1[2]}-s_{1[1]})^2}{(s_{2[11]}+s_{2[22]})^2}\right] \\
&\quad -\frac{\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]^2}{4\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}, \\
\text{covariance effect} &:= \frac{1}{2}\mathbb{E}\left[\frac{(\tilde{w}_{1[1]}-\tilde{w}_{1[2]})(s_{1[2]}-s_{1[1]})}{s_{2[11]}+s_{2[22]}}\right] \\
&\quad -\frac{\mathbb{E}\left[\frac{\tilde{w}_{1[1]}s_{2[22]}+\tilde{w}_{1[2]}s_{2[11]}}{s_{2[11]}+s_{2[22]}}\right]\mathbb{E}\left[\frac{(\tilde{w}_{2[11]}s_{2[22]}+\tilde{w}_{2[12]}s_{2[11]}-\tilde{w}_{2[22]}s_{2[11]}-\tilde{w}_{2[12]}s_{2[22]})(s_{1[2]}-s_{1[1]})}{(s_{2[11]}+s_{2[22]})^2}\right]}{2\mathbb{E}\left[\frac{\tilde{w}_{2[11]}s_{2[22]}^2+\tilde{w}_{2[22]}s_{2[11]}^2+2\tilde{w}_{2[12]}s_{2[11]}s_{2[22]}}{(s_{2[11]}+s_{2[22]})^2}\right]}.
\end{aligned}
$$

The various coefficients of comparative advantage between regulations R, R' can then be calculated via the relation

$$\Delta^{R;R'} := \mathbb{E}\tilde{W}^R - \mathbb{E}\tilde{W}^{R'}.$$

Chapter 4

Fair Compensations for Heterogeneous Labor Inputs

4.1 Introduction

Many people express unease about disproportionate relative wages. The former German secretary of labor Franz Müntefering, for instance, stated in an interview in 2016 with the Süddeutsche Zeitung that there are "immoral high wages for managers who earn six hundred times as much as nurses".[1] Similarly, Bernie Sanders asked via Twitter on July 12, 2018: "Does Disney CEO Bob Iger have a good explanation for why he is being compensated more than $400 million while workers at Disneyland are homeless and relying on food stamps to feed their families?"[2] These political statements express the concern that relative wages for different types of labor are 'unfair', because they are disproportionate to each other. Because labor inputs are seldom homogeneous in reality, it is not immediately clear in which sense wages are 'out of proportion'. This paper tries to shed light on this question experimentally to better understand why some people might perceive some wage relations as unfair and others not. More precisely, we study which characteristics of an input determine how large the fair output share of its contributor should be, and how this differs between individuals.

There are already experimental studies about the fair distribution of a joint output, for instance Cappelen et al. (2010) or earlier studies reviewed in Konow (2003). These studies support the idea that people are guided by the 'equity principle' – sometimes also called the 'proportionality principle' – when they judge the distribution of joint outputs. The equity principle states that the share of a joint output that a person receives should be equal to their share in the inputs, see Adams (1965) (or Cappelen and Tungodden (2017) for a more recent discussion of the equity principle). Given its focus on

[1] `www.sueddeutsche.de/wirtschaft/reden-wir-ueber-geld-mit-franz-muentefering-das-ganze-jahr-urlaub-ist-auch-kein-urlaub-1.3163179?reduced=true`. Own translation.

[2] `twitter.com/sensanders/status/1017776415234842625?`.

proportional compensations, the equity principle is a useful concept for understanding the fairness concerns expressed in the quotes above. The previous experimental studies of the equity principle, however, have one important shortcoming: they have only investigated situations with homogeneous inputs. In such cases the size of inputs is simply given by their quantity. In situations with heterogeneous inputs (as in most real-world cases), the meaning and applicability of the equity principle becomes more difficult, as pointed out by Güth (1994).

This paper proposes that one can extend the equity principle to situations with heterogeneous inputs if one uses an appropriate scale for measuring and comparing the inputs. More specifically, we propose that there is such a scale in the form of weighted input quantities, where the weights depend on the *relative burden of input provision.* This relative burden might be assessed differently by different people, but it can be systematically measured. Consider a person who assesses task A as three times as tedious as task B and who regards tediousness as a burden worth compensating for. In a situation in which the quantity of input A is half the quantity of input B, this person would allocate 3/2 times as much of the output to input A as to input B (or equivalently: input A should receive 60% of the total output).

Given the hypothesis just described, we chose an experimental setup to determine the weights relevant for the fair distribution among heterogeneous inputs in a systematic and controlled way. Our experiment, which we have conducted on Amazon MTurk with US residents, comprises several scenarios in which two people (called 'workers') perform different real-effort tasks that lead to a joint payoff. For each scenario we have asked impartial 'spectators' to split the output between the two input providers in a way they regard as fair. When the spectators decide anonymously about the distribution, they have no stake in the distributed output.[3] In addition they are informed that the workers can chose neither the type nor the amount of input they provide. This ensures that there is no strategic interaction between the distribution decision and the input contribution.

Across scenarios we varied the quantity, the marginal productivity and the type of input independently. The heterogeneous types of input are mathematical calculations and a ball-catching exercise. While quantity and marginal productivity are objective parameters, the two types of input can be perceived differently by different people. In order to understand which characteristics of an input influence the spectators' choice of a fair distribution, we have asked the spectators at the beginning of the experiment to assess the two types of input along various dimensions. These dimensions include, for instance, the intellectual difficulty, the time required for completion and the tediousness of the tasks. By regressing the spectators' choices of fair compensations on the parameters

[3]If the decision makers had a stake in the distributive outcome, one would expect that they adjust their normative preferences depending on their stake in the game in order to reduce "cognitive dissonance" – as illustrated by Konow (2000).

and perceived characteristics of the inputs, we could establish a key result of this paper: the relevant determinants of the spectators' choice of a fair distribution are the quantity, the time required and the tediousness of the inputs. This result provides support for the existence of an 'extended' equity principle. The intellectual difficulty of an input seems to have a positive impact on the fair compensation as well, but the effect is small and driven by only a subgroup of the spectators (those with a bachelors degree or a yearly income above \$35k). The marginal productivity, in contrast, does not contribute positively to the fair compensation.

If in reality wages are determined by marginal productivities (as suggested by neoclassical economics), then the results of our experiment offer an explanation for the quotes cited above. Given that people want to reward for the burden of input provision related to the tediousness, toil and time of a particular task, people will perceive a market outcome as unfair, if the market prices do not reflect this burden of input provision, but only the marginal productivities.

While this result holds for the average spectator in our experiment, people might differ in the weights they assign to the various input characteristics. To address the question of heterogeneity among spectators we proceed in two ways. First, we control for personal traits like socioeconomic status. As mentioned before, spectators with higher incomes and higher education put more weight on productivity and intellectual difficulty of an input. The weights given to tedious, toilsome and time demanding tasks are independent of the income or education of the spectators. Second, for each spectator we identify which single specific extension of the equity principle can explain their distributive decision best. We find that 'tediousness-extended' equity is the most frequent extension among the spectators, followed by 'time-extended' equity and 'intellectual difficulty-extended' equity. 'Toil-extended' equity is less prevalent and 'productivity-extended' equity is the least frequent extension.

In order to study the robustness of the results, the experiment includes two test scenarios. First, we want to address the potential problem of reverse causality: it could be the case that the subjective assessments do not determine the distributive preferences but that the latter determine the former. To test the hypothesis that the assessments have a causal impact on distributive preferences, we inform the spectators that the calculation is more toilsome than they initially expected. This information leads indeed to a significant increase of the compensation for the worker performing the calculations. Second, we want to test whether the results change, when workers can freely choose their own input quantity. We find that this variation does not systematically change the fair distribution of the output relative to the baseline.

In the last part of the experiment we study whether our results are consistent with consequentialist normative preferences. Normative preferences are consequentialist when they depend only on final outcomes and not on intentions, frames, procedures, etc..

Welfarism, as the dominant normative approach in the public finance literature, is an important example of a consequentialist theory. To test whether the distributive choices of spectators are consistent with consequentialism, two scenarios are presented for which a consequentialist would choose the same distribution, while a person that adheres to a non-consequentialist interpretation of the equity principle would choose differently. Comparing the spectators' choices in the two scenarios, we can show that the distributive choices of the spectators are at odds with consequentialism (and therefore with welfarism).

To sum up, the contribution of this paper is threefold. First, we develop an experimental approach to systematically study distributional preferences in case of heterogeneous inputs to a joint output. While we consider a particular selection of input characteristics, the experimental approach can also be applied to other cases with heterogeneous inputs. Second, in a first application of this approach, we test whether spectators behave consistently with an extended equity principle. We find that spectators extend the equity principle for the dimensions of time, toil and tediousness but not for productivity or intellectual difficulty (although more educated and higher earning people extended the equity principle for the latter two as well). Third, we show experimentally that the distributional preferences of the people are inconsistent with welfarism and, more generally, consequentialism.

Additional Related Literature There is a growing number of experiments that try to measure distributive preferences in economic settings in which several people contribute to a joint output. In contrast to this study, all previous experiments focused on homogeneous types of inputs. The overview by Konow (2003) and the more recent study by Cappelen et al. (2010) have already been mentioned. In addition, there is a series of papers on distributive preferences in case of risky payoffs: Cappelen et al. (2013) find that most people want to equalize initial chances, while there is some support for equalizing the risky outcomes. In addition they show that people are less in favor of equalizing risky payoffs if the agents have deliberately chosen a risky game. Mollerstrom et al. (2015) extend this work by studying the interaction between controllable and uncontrollable luck. Cappelen et al. (2019) demonstrate that people with meritocratic ideals become more egalitarian, if they do not know whether a difference in payoffs is caused by different merits or by luck. Almås et al. (2020) compare the distributive preferences between the US and Norway and find that people in both countries are similarly meritocratic, but Norwegians are more egalitarian while Americans are more libertarian. Schildberg-Hörisch (2010) has shown that decision makers with a stake in a risky distribution prefer more ex-post equalization, if they are behind a veil of ignorance with respect to their position. In our study, we deliberately exclude risk in order to focus on other characteristics of real effort tasks. Nevertheless, our study shares many similarities in scope and methodology with the studies discussed above. However, they also choose some ex-post equalization in knowledge of a good position for them. Herz and Taubinsky (2017) show that the perception of fair economic outcomes is path-dependent, as previously realized prices constitute a reference point for the further perception of price levels. Finally Gantner and Kerschbamer (2016) do not focus on allocative fairness but instead they study the perceived fairness of various distributive procedures.

Besides experimental studies there are also some surveys that try to elicit the distributive preferences of people. Schokkaert and Lagrou (1983) ask employed people which features of a job justify a higher income. While they find that the effort spend on a job can justify income differences, they do not further explore how the "amount" of effort can be measured and compared across heterogeneous jobs. In a related vignette study, Schokkaert and Overlaet (1989) find that the fair distribution in a setting with homogeneous inputs agrees with the 'equity principle': the compensation should be proportional to the size of the input. Konow (1996) further develops this line of research and shows in a series of vignette studies that people distinguish between exogenously given productivity differences and endogenously chosen variables. These studies inform our selection of characteristics of real effort tasks that we investigate in our experiment. We provide a detailed discussion of these characteristics in Section 4.3. Weinzierl (2014) uses a survey to show that preferences concerning tax schedules are influenced by the concept of 'equal sacrifice', meaning that utility losses due to taxation should be equalized.

In addition there is an extensive literature studying (increasing) income inequality from a theoretical and empirical point of view. E.g., Piketty and Saez (2003), Goldin and Katz (2007) and Autor and Dorn (2013) document a stark increase of top income shares, a stark increase of educational wage differentials and - less pronounced - a wage polarization of the labor market over the last decades, respectively. The theoretical literature studying the optimal response of the income tax to increasing inequality provides diverging recommendations, depending on the causes for the increase in inequality: Ales et al. (2015) show that skill-biased technical change provides a rationale for higher marginal taxes at the top. Arriving at a similar conclusion, Ales and Sleet (2016) show that CEOs should face high marginal taxes (albeit only in the absence of profit taxation). Scheuer and Werning (2017), on the other hand, provide a rationale for lower (or unchanged) marginal taxes at the top due to superstar effects.

The rest of the paper is organized as follows: Section 4.2 describes the experimental design, Section 4.3 develops theoretical predictions for the experiment, Section 4.4 explains the empirical strategy, Section 4.5 provides descriptive statistics, Section 4.6 contains the results of the empirical analysis and Section 4.7 concludes. Two alternative regression analyses, additional tables and graphs, the experimental instructions and the Stata code can be found in Appendices 4.A, 4.B, 4.C, 4.D and 4.E, respectively.

4.2 Experimental Design

Participants of the experiment are randomly assigned to two groups. The first group consists of (pairs of) so-called 'workers' and the second group consists of so-called 'spectators'. First, spectators should assess two real-effort tasks in several dimensions. Second, we ask spectators to choose a 'fair' distribution of money between workers in various scenarios where workers complete these real-effort tasks. Third, spectators fill out a general questionnaire. Finally, for each pair of workers one scenario and one spectator is randomly selected and the workers have to complete the corresponding tasks and receive their compensation according to the spectator's decision in this scenario.

By varying different characteristics of the tasks across the scenarios (i.e., the quantity, the productivity, or the type), we can measure the impact of these characteristics on the fair distribution of money. In particular we can measure the impact of the subjective assessments of the tasks on the distribution. This procedure provides a novel, systematic method for studying which characteristics of heterogeneous inputs determine the fair distribution of the payoff among these inputs. Since the payoffs of the spectators do not depend on their decisions, the measurement of social preferences is not distorted by self-interested considerations. Nevertheless spectators are incentivized to reveal their social preferences because their decisions have real consequences for other people.

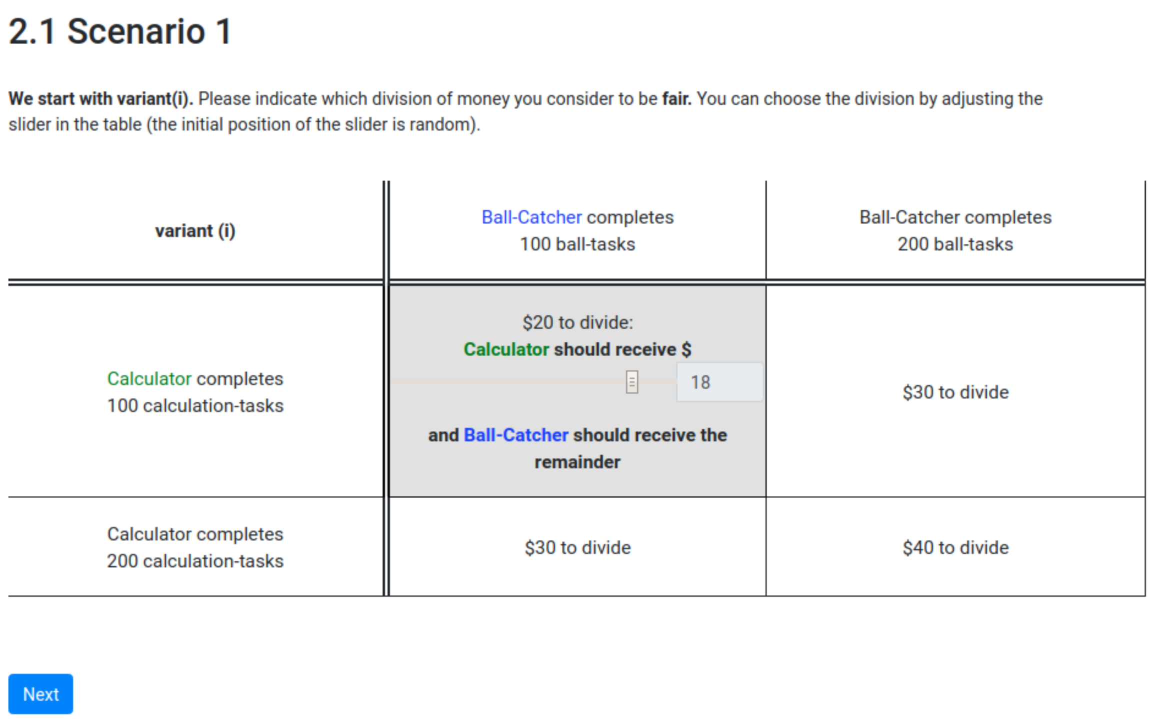
The experiment was conducted as follows. In March 2019 we recruited 291 US residents as spectators and ten US residents as workers via Amazon MTurk. We restricted the sample to subjects who completed at least 100 HITs (Human Intelligence Tasks) before and had a HIT Approval Rate of at least 95%. We chose to restrict our sample in this way to ensure that the subjects were sufficiently familiar with the platform and to ensure a high quality of the answers. However, as e.g. documented by Chandler et al. (2014), MTurkers might not be representative for the general population and this is especially true for professional "Super Turkers". We test afterwards whether the results differ by the (self-reported) number of experiments completed previously and find no effect. In addition, in order to alleviate concerns that participants just maximize their payment per minute, we did not provide monetary incentives for quick answers, appealed to the good will of participants and asked multiple control questions.

Spectators First the spectators are informed about the proceedings of the experiment (assessment, division of money, questionnaire). Then each spectator is randomly assigned to one pair of workers and it is made salient to the spectator that their upcoming decisions can affect real people and that they should therefore pay proper attention to their decisions. A spectator gets a fixed payment of \$5 (independently of their decisions). Spectators are informed that each worker receives a fixed payment of \$10 plus a payment depending on the decisions of the assigned spectator (but independently of the workers decisions). We check via a control question that the spectators understand that workers can neither choose the type nor the number of tasks they have to complete. Throughout the experiment we ask control questions to make sure that the spectators understand what is going on at each step (we ask five control questions in total). We hope that a reasonable quality of the data is ensured by the combination of appealing to the good will of spectators, making it salient that their decisions affect real people, repeatedly asking control questions and paying generously. The complete instructions can be found in Appendix 4.D.

Assessment First spectators are asked to assess two tasks, the *ball-task* and the *calculation-task*, in various dimensions. For this they have to complete one of each task. One ball-task consists of catching ten green balls falling from the top to the bottom of the screen by moving a red ball left or right and one calculation-task consists of solving ten simple arithmetic exercises. Subsequently the spectators are asked to assess how *tedious, intellectually demanding, toilsome* and *time consuming* these tasks are relative to each other. For each spectator we thus collect four data points of the form "100 calculation tasks are x-times as tedious/intellectually demanding/toilsome/time consuming as 100 ball-tasks", where x is some positive number.

Division of Money The second step of the experiment consists of five different scenarios. In each scenario we present tables like the one in Figure 4.1 to the spectators. The first column and the first row contain information about the type and quantity of the tasks that the workers have to complete in this scenario. The remaining cells ask the spectators to divide a given amount of money between the two workers (we refer to the two workers as "Ball-Catcher" and "Calculator"). More precisely, for all four cells the spectators are asked: "Please indicate which division of money you consider to be **fair**. You can choose the division by adjusting the slider in the table." We check via a control question whether the spectators understand that the sliders control the amounts of money that the Calculator and the Ball-Catcher receive. Both, the sequence of cells presented to the spectators and the initial position of the sliders are random to reduce the potential effects of path and reference point dependency. Throughout the experiment we show a pocket calculator at the bottom left of the screen in order to allow for calculations by the spectators. After completing a scenario (i.e. after choosing the fair division of money for all cells) the spectators are given the opportunity to revise their decision. This basic structure holds for all scenarios. Let us now describe the specific details of the five scenarios.

The baseline scenario, called *Scenario 1(i)*, is characterized by the following features. Workers complete different tasks (calculation-tasks or ball-tasks) which are equally productive (the output table is symmetric). Workers receive a fixed payment of $10 and



2.1 Scenario 1

We start with variant(i). Please indicate which division of money you consider to be **fair.** You can choose the division by adjusting the slider in the table (the initial position of the slider is random).

variant (i)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$20 to divide: **Calculator should receive $** 18 **and Ball-Catcher should receive the remainder**	$30 to divide
Calculator completes 200 calculation-tasks	$30 to divide	$40 to divide

Next

Figure 4.1: Example of a division table.

cannot choose the number of tasks they complete (i.e. whether they complete 100 or 200 tasks). Spectators have no information about the workers' assessment of the tasks. For the remaining scenarios we alter the above aspects one at a time. In *Scenario 1(ii)* the ball-catcher is twice as productive as the calculator, i.e. an increase in ball-tasks increases output by twice as much as an increase in calculation-tasks. In order to ensure that the spectators are aware of the different productivities, we test whether they were able to calculate marginal products. In *Scenario 2* the fixed payment of workers is reduced from \$10 to \$0, while the amount of money that the spectators can divide is increased by \$20 for each cell. Based on this scenario we test whether spectators respond to this inconsequential variation in the procedure of payments.[4] In *Scenario 3* workers can choose the number of tasks they want to complete given the spectators output distribution in *Scenario 1(i)*. The spectators are then asked how they want to distribute an additional amount of money among the workers, knowing the workers' quantity choice.[5] Based on this scenario we test whether spectators take into account whether or not work-

[4]Between *Scenario 2* and *Scenario 3* we ask a trivial control question ("How many members does a pair contain?") in order to check whether the spectators still pay attention. Between *Scenario 3* and *Scenario 4* we ask the spectators to type the number "50" as our final control question.

[5]More specifically, spectators are presented the following situation: "Given the fair division of money you have set before [here we show the spectator's choice from *Scenario 1(i)*], Calculator chooses to complete 100 calculation-tasks and Ball-Catcher chooses to complete 100 ball-tasks [...]. You can now divide \$30 between them, but you have to give Calculator at least [as much as before] and Ball-Catcher at least [as much as before]. Please indicate which division of money you consider to be **fair**." In addition

ers can freely choose how much they work. In *Scenario 4* spectators are confronted with the possible situation in which the Calculator and the Ball-Catcher agree that 100 calculation-tasks are twice as toilsome as 100 ball-tasks. Based on this scenario we test whether spectators respond to exogenous information about the toil of factor provision (in contrast to the self-assessed toil in the other scenarios). In *Scenario 5* both workers complete calculation tasks. By contrasting this scenario with Scenario 1, one can identify the impact of input heterogeneity on the decisions of the spectators.

Questionnaire The questionnaire consists of four blocks of questions: First we ask demographic questions (country of birth, age, gender, highest educational degree, occupation, net labor income, number of completed experiments). In the second block spectators should describe the rules or principles they followed while dividing the money. In the third block spectators should rate various policy statements on a 5-point Likert scale.[6] In the last block spectators should again rate statements on the 'fair determinants' of labor incomes on a 5-point Likert scale.[7] After the experiment we disclose the intent of the experiments to the participants and ask them whether they perceived any part of the experiment as biased or confusing.

Workers The design for the ten workers is quite simple, since their role was mainly to incentivize the behavior of the spectators. We recruited pairs of workers on MTurk and they were asked to fulfill tasks of the following kind: "You have to complete [x] calculation-tasks (i.e. solving simple calculations tasks of the form $4 \times 5 + 7$) for a monetary reward of \$ [y]." The specification of x and y resulted from a random draw from the set of scenarios and from the set of distributive choices made by the spectators. Workers could not take any decision (apart from refusing to take part in the study at all).

4.3 Theory and Hypotheses

This section describes the theoretical background of the experiment and develops hypotheses concerning the fair division of money chosen by the spectators. The experiment studies whether and how the 'equity principle' can explain distributive choices in situa-

spectators are asked the same question again for the case of 100 calculation-tasks/200 ball-tasks and the possibility to distribute $40.

[6]The statements are "Taxes on high labor incomes .../ Maximum wages .../ Subsidies for low wages .../ Minimum wages ... ... lead to more fairness" and the order of statements is randomized.

[7]We ask for each of the following job features whether this feature should influence the 'fair compensation' of a job: value for the employer/toil/intellectual difficulty/what the employer offers/talent necessary/working hours/tediousness/value for society/education and qualification necessary. The order in which we presented the different features was again randomized.

tions with heterogeneous inputs and a joint output. This principle, which is also known as the 'proportionality principle', can be stated as:

The share of output that a person receives should be equal to their share of the inputs.

– or equivalently –

The relative compensation for the provision of an input should be equal to its relative size.

Applied to the setting in our experiment, the principle can be expressed as:

$$\frac{\text{compensation}_{\text{calculation}}}{\text{compensation}_{\text{calculation}} + \text{compensation}_{\text{ball}}} = \frac{\text{input}_{\text{calculation}}}{\text{input}_{\text{calculation}} + \text{input}_{\text{ball}}} \tag{4.1}$$

– or equivalently –

$$\frac{\text{compensation}_{\text{calculation}}}{\text{compensation}_{\text{ball}}} = \frac{\text{input}_{\text{calculation}}}{\text{input}_{\text{ball}}}\,. \tag{4.2}$$

In modern social science Adams (1965) was the first to suggest that this equity principle guides people who decide about the fair distribution of a joint output. From a theoretical point of view Cappelen and Tungodden (2017) show that this principle can be derived from basic theoretical considerations of egalitarianism and liberalism. In addition, many empirical studies (surveys as well as lab and online experiments) confirm that people tend to follow this principle when they choose a fair distribution of joint output – see, for instance, Cappelen et al. (2007, 2010). These empirical studies, however, have focused on situations with homogeneous inputs.

The application of the equity principle requires a comparison of the relative sizes of the compensations and a comparison of the relative sizes of the inputs – see Eq. (4.2). In most economic applications (and in our setting) compensations are measured in money and are therefore directly comparable. In case of homogeneous inputs (as in previous studies), it is also straightforward to compare the size of the inputs by their relative quantity: performing a certain task twice is twice the contribution as performing the same task once. In case of heterogeneous inputs, however, the size of an input might not only depend on the quantity of an input but also on other characteristics that distinguish the inputs. For instance, if one task is perceived as more tedious than the other, performing the first task might be regarded as a larger contribution than performing the other task. In order to account for such additional characteristics, we propose to extend the equity principle by weighting the quantities:

$$\frac{\text{compensation}_{\text{calculation}}}{\text{compensation}_{\text{ball}}} = \frac{\text{quantity}_{\text{calculation}} \cdot \text{weight}_{\text{calculation}}}{\text{quantity}_{\text{ball}} \cdot \text{weight}_{\text{ball}}}. \tag{4.3}$$

The weight of a task is a function of the task's characteristic as they are assessed by the individual who chooses the compensations. Therefore the weights can differ between individuals for two reasons: first, individuals might assess tasks differently; and second, they might differ in the importance they attach to a given characteristic. Note that an individual applying the equity principle only needs to assess the tasks relative to each other, not in absolute terms. Consider an example in which, first, the spectator in our experiment regards calculation-tasks as twice as intellectually demanding as ball-tasks, and second, the spectator regards the intellectual demand of an input as the only characteristic of an input that determines the fair compensation. If the spectator follows the extended equity principle, the compensation assigned to each calculation-task will be twice as large as the compensation assigned to each ball-task. In the example it has been assumed that the weight depends linearly on the assessment. For simplicity the following analysis employs a linear relationship as well.[8]

Which characteristics of an input are relevant for choosing the fair compensation? We will answer this question empirically. For practical reasons, we have to focus on a short list of candidate characteristics and study their effects on the distributive choice. We have chosen a first set of characteristics in this study according to two criteria: first, the characteristics can be represented by simple tasks that allow for a clear experimental setup;[9] second, they capture relevant aspects of real-world jobs. Guided by these criteria, we select the following list of work characteristics:

- the quantity of tasks completed (*quant*),
- the marginal productivity of the task, i.e. the amount by which output increase when this input increases (*prod*),
- how tedious the task is (*tedious*),
- how intellectually demanding the task is (*intdem*),
- how toilsome the task is (*toilsome*) and
- the time required for completing the task (denoted by *time*).

The *emphasized* abbreviations in parenthesis denote the relative assessment of the calculation-task relative to the ball-task. If, for instance, the spectator assesses the calculation-task as twice as intellectually demanding as the ball-task, we write *intdem* = 2.

[8]Despite being simple there are further theoretical arguments that support this simple relationship, cf. Cappelen and Tungodden (2017).

[9]"Responsibility", for instance, would be an interesting and probably relevant category to assess an input's contribution to a joint output. But to test the role of responsibility in an experiment would require to give participants some discretion in the completion of their tasks. And that would make it hard to distinguish whether the spectators choose a payoff distribution due to normative preferences or in order to implement certain incentive structures.

While *tedious* and *toilsome* have a similar meaning, they have different connotations: the first adjective is more closely related to boring and monotonous work, whereas the latter is more closely related to hard and laborious work. Note that both terms refer to a property of the work, in contrast to the willingness to work which is often referred to as effort in the literature. Productivity and quantity are not subjective assessments, but objective properties of an input (in contrast to the other characteristics). Although time is an objective quantity in principle, our analysis is based on subjective expectations about the time required for the tasks, because spectators have to choose the fair distribution before the workers perform the tasks. Note that, while the concept of productivity has many different uses in economics, in our case the productivity of an input means the increase in output when this input increases.

Based on the concepts introduced above, we want to formulate testable empirical hypotheses. Denoting $\frac{\text{compensation}_{\text{calculation}}}{\text{compensation}_{\text{ball}}}$ as *comp* and taking logs, we can rewrite the extended equity principle in Eq. (4.3) as follows:

$$\begin{aligned} \ln comp = \beta_0 + \beta_1 \ln quant + \beta_2 \ln prod + \beta_3 \ln tedious \\ + \beta_4 \ln intdem + \beta_5 \ln toil + \beta_6 \ln time\,. \end{aligned} \tag{4.4}$$

Econometric details of the regressions are postponed until Section 4.4. Suppose that the spectators distribute the output according to Eq. (4.3) and that they weigh an input only by its tediousness. The result of the logarithmic regression in Eq. (4.4) in this case would be that all betas are zero apart from β_1 and β_3, which would be equal to one. As a second example, suppose that the spectators follow the equity principle, but do not care about the heterogeneity of the inputs. In that case all betas except for β_1 would be zero. Finally, if they were not influenced by any version of the equity principle, then all betas would be zero. This would correspond to a strict 50/50 division, independent of the parameters of the scenario at hand.

As mentioned above, there is both empirical and theoretical support for the hypothesis that people follow the equity principle when they make distributive decisions. We thus expect that β_1 is significant in our experiment as well. Assuming that the input characteristics listed above (*time*, *intdem*, *tedious* and *toil*) are important dimensions by which people assess tasks, we expect that some of the coefficients β_3 to β_6 are significant. Alternatively one could formulate the hypothesis that these characteristics have a strictly positive impact. But we do not want to exclude the possibility that people penalize rather than reward certain characteristics. Consequently we use two-sided tests in the empirical part.

While these four characteristics are immanent to the tasks, the productivity of a task is a feature of the environment in which the input is provided. Given this difference, we expect that the productivity of an input has no impact on normative valuations of inputs (like the equity principle). This expectation is also in line with results of previous experimental studies with homogeneous inputs like Greenberg (1979) and Konow (2000), which have found that the productivity of an input at most has a weak impact on the spectator's distributive choices.[10] Finally, there is no theoretical reason to expect a non-zero constant: a non-zero constant would imply that individual 1 is treated differently than individual 2, because one is named "1" an the other "2" and not because they complete different tasks. To sum up, we have formed the following hypotheses that shall be tested in the experiment.

Hypothesis 1 *Equity Principle – Regression Analysis*

a) The fair compensation depends on the quantity of an input ($\beta_1 \neq 0$).

b) The fair compensation depends on at least one dimension of assessment ($\beta_i \neq 0$ for at least one $i = 3, 4, 5, 6$).

c) The fair compensation is independent of the productivity of an input and independent of the constant ($\beta_2 = \beta_0 = 0$).

While the regression analysis sheds light on the average importance of different characteristics, we want to study the heterogeneity among spectators in greater detail. For this purpose we classify spectators by the characteristic that can best explain their distributive choices. The exact procedure is explained in Section 4.4. Following the same reasoning that leads to Hypothesis 1, this alternative approach leads to the following hypothesis:

Hypothesis 2 *Equity Principle – Classification of Spectators*

a) A considerable fraction of the population follows an extended equity principle that weighs quantities by either intellectual difficulty, tediousness, toil or time.

b) The fraction of the population weighing quantities by productivity is negligible.

We also want to understand how the empirical observations in our experiment relate to the theoretical literature concerned with questions of distribution. Much of this literature is dominated by consequentialism, in particular welfarism. Consequentialism states that social situations should be evaluated solely on the basis of final outcomes and not intentions, procedures, frames, etc. Welfarism demands furthermore that social situations should be evaluated solely on the basis of the realized "utilities" of the involved agents, which means "utilities" are the only relevant outcomes. One clarification concerning our

[10] An experimental study by Cappelen et al. (2007) has identified some spectators who did not want to correct an output distribution that was determined by differing productivities of homogeneous inputs. But this share of spectators was small and the experimental setup was very different to ours, as the participants that corresponded to our 'workers' could choose the quantity of their inputs and these inputs were investments rather than real-effort tasks.

understanding of consequentialism is in order: for the purpose of this paper we define a person to be consequentialist if and only if they evaluate situations in terms of their consequences. In particular, individuals behaving according to "context-dependent welfarism" as in Bernheim and Rangel (2009) are no consequentialists in the sense of this article.[11]

The equity principle proposed in this paper, in contrast, is non-consequentialist since it refers to the distribution of resources in relation to work performed. More precisely, the evaluation of social situations depends on the interpretation of actions and resources as inputs and outputs.[12] While welfarism (or consequentialism more generally) is dominant in economic theory, it is still unclear whether people actually share these norms. We therefore want to test whether the choices of spectators are compatible with consequentialists norms or differ significantly from these.

For this purpose, we have constructed Scenario 2 that is identical to Scenario 1(i) apart from the following variation: the fixed payments for the workers are decreased in in Scenario 2 while the output related to the tasks is increased accordingly (such that the total amount of money paid to the workers remains the same). This variation should be irrelevant for a spectator who follows a consequentialistic norm. A consequentialistic spectator would choose the distributions such that the final allocation of payoffs (consisting of the fixed payments and the shares of the distributed output) is the same in both scenarios. If, in contrast, the relation between inputs and the share of distributed output matters (as in case of the equity principle), then the two scenarios are regarded as different and the allocation of payoffs chosen by the spectators will differ across the two scenarios. In order to test the empirical relevance of consequentialistic norms, we will thus test the following hypothesis:

Hypothesis 3 *Consequentialism*

The final allocations of output in Scenario 2 and Scenario 1(i) differ from each other

The setup of our experiment differs from other experiments as the workers cannot choose the quantity of the input they have to provide. Cappelen et al. (2010); Konow (1996) and others have documented that the ability of input providers to choose the quantity of their input affects the distribution of output that participants regard as fair. While these effects are interesting, they would obfuscate how the heterogeneity of inputs affects the fair distribution of output. Consider, e.g., a worker who chooses to complete a high number of a given task and a spectator who distributes a relatively high output share to this worker. Does the spectator want to reward certain characteristics of this task

[11] Also, a person who tries but fails to behave in a consequentialist manner, is not a consequentialist in the sense of this article.

[12] In principle - but in contrast to the previous literature - one could apply the equity principle to all resources available, resulting from labor or not. This would be a consequentialist but non-welfarist version of the equity principle.

or the industriousness of the individual worker? In order to disentangle these potential motives of the spectators, we deliberately excluded the choice of input quantities from our main analysis.

Nevertheless, we want to check the robustness of our result. In Scenario 3 we test whether the impact of the input characteristics on the distribution of output changes, if one allows for a choice of quantities by the workers. For this purpose, workers are confronted with a fair distribution that a spectator chose in Scenario 1(i). The workers are then asked how many tasks they would like to complete given this distribution. Knowing this quantity choice, the same spectator then decides again about the fair distribution of output between the workers, while the amount of output is bigger than in Scenario 1(i).[13] A spectator whose fairness ideals are not affected by the ability of workers to choose, should not change their (relative) distribution of output. This leads to our last hypothesis:

Hypothesis 4 *Freedom of Choice*

The effect of the input characteristics on the fair compensations does not differ between Scenario 1(i) and Scenario 3.

4.4 Empirical Strategy

In our main empirical specification we use Scenarios 1(i), 1(ii) and 5 only. In each of these three scenarios we ask each spectator i four times to divide money between the workers. There are thus twelve decisions and we refer to them as *cells*, which we number as $c = 1, ..., 12$.[14] The ratio of worker compensations that spectator i choses in cell c is denoted by $comp_{ic}$ (as introduced in Section 4.3). The ratios of the quantity and productivity of the worker's tasks are denoted as $quant_c$ and $prod_c$, respectively. They are the same for each spectator, but they vary across the cells.[15] The relative assessments of the tasks by spectator i are denoted as $tedious_{ic}, intdem_{ic}, toilsome_{ic}$, and $time_{ic}$. The assessments vary across cells because the inputs are homogeneous in Scenario 5 (while they are heterogeneous in all other scenarios).

[13]The amount of output is bigger to allow the spectator to alter the relative distribution without making workers worse off (compared to Scenario 1(i)). Otherwise the spectators might feel compelled to fulfill the workers' expectations concerning their compensation.

[14]The top left cell in Scenario 1(i) is $c = 1$, the top right cell in Scenario 1(i) is $c = 2$ and so forth until the bottom right cell in Scenario 5 given as $c = 12$.

[15]Each of the following set of cells has a different value of $quant_c$: $quant_c = 1$ for $c \in \{1, 4, 5, 8, 9, 12\}$, $quant_c = 1/2$ for $c \in \{2, 6, 10\}$, $quant_c = 2$ for $c \in \{3, 7, 11\}$. And each of the following set of cells has a different value of $prod_c$: $prod_c = 1$ for $c \in \{1, 2, 3, 4, 9, 10, 11, 12\}$, $prod_c = 1/2$ for $c \in \{5, 6, 7, 8\}$.

Regression Analysis Our main regression is described by the following equation:

$$\begin{aligned} \ln comp_{ic} = \beta_{0i} + \beta_{1i} \ln quant_c + \beta_{2i} \ln prod_c + \beta_{3i} \ln tedious_{ic} \\ + \beta_{4i} \ln intdem_{ic} + \beta_{5i} \ln toilsome_{ic} + \beta_{6i} \ln time_{ic} + \varepsilon_{ic}\,, \end{aligned} \tag{4.5}$$

where the coefficients consist of a common component and a spectator-specific one: $\boldsymbol{\beta}_i = \boldsymbol{\beta} + \boldsymbol{u}_i$, where the spectator-specific component satisfies $E[\mathbf{u}_i] = \mathbf{0}$ and $V[\mathbf{u}_i] = \boldsymbol{\sigma}_u^2\mathbf{I}$. Using this 'mixed model' we can study the heterogenity among the spectators concerning the weights that they assign to the different input characteristics (see Rabe-Hesketh and Skrondal (2008) for an introduction to mixed models). For instance, β_3 is the average effect of the perceived tediousness of a task on its fair compensation, while σ_{u3} measures the heterogeneity of this effect across the different spectators. The regression in (4.5) corresponds directly to the hypothesized relationship between the ratio of compensations and the ratios of input characteristics expressed in Eq. (4.4): A 1% increase in spectator i's assessment of the relative tediousness of the calculation task leads to an increase in the relative compensation of the calculation task by β_{3i}%.

The main regression uses assessments on a continuous scale. However, it might be the case that some spectators cannot actually assess tasks on a continuous scale but can only rank them. They might be able to say that task x is more tedious than y, but they might not be able to specify by how many percent the tasks differ with respect to their tediousness.[16] This issue is addressed in Appendix 4.A, where the continuous ratios in Eq. (4.5) are replaced by dummies.

Given that the input characteristics are not exogenous parameters in this experiment, one should check whether these characteristics drive the distributive choices (and not the other way around). In order to test this, Scenario 4 has been designed such that it implies an exogeneous variation of the relative toil of the tasks. By including a dummy for Scenario 4 in one specification of the regression, we will test whether this variation of the toil leads to a significant change in the relative compensation of the inputs. If this test is positive, it shows that input characteristics have a direct impact on the fair distribution chosen by the spectators.

Classification of Spectators The regression analysis shows that there is heterogeneity in the importance attached to different input characteristics. However, it does not allow for a simple assessment of the overall prevalence of the different input characteristics - and of the importance of different versions of the equity principle. To complement the regression analysis we use a complementary approach to study the importance of the different input characteristics as well that disagreement of the spectators about this

[16] Although we forced the spectators to provide continuous assessments, that does not imply that these numbers are meaningful.

importance. We classify the spectators by the extension of the equity principle that fits to their choices best. More precisely, we determine for each spectator i the dominant input characteristics d_i as follows:

$$d_i \in \arg\min_{d} \frac{1}{p} \sum_{c=1}^{12} \left| \ln comp_{ic} - \ln comp_{ic}^{d} \right|^{p}, \tag{4.6}$$

where $d \in \{tedious, time, intdem, toilsome, prod, 1, quant^{-1}\}$ and $comp_{ic}^{d} = quant_c \cdot d_{ic}$ is the fair compensation according to an equity principle in which only the weight d matters. While the first five cases are self-explanatory, the last two deserve clarification: $d = 1$ implies $comp_{ic}^{d} = quant_c$ and this corresponds to the standard *equity* principle (in contrast to an extended equity principle); $d = quant^{-1}$ implies $comp_{ic}^{d} = 1$ and we will refer to this case as *equality*. The parameter p determines how harshly the loss function punishes big deviations from a given version of the extended equity principle compared to smaller deviations. In our setup there is no good theoretical reason to favor a specific value of p over another. For this reason we present results for different values of p. The classification of distributive norms by means of such loss functions has been frequently used in previous literature on fairness ideals, see e.g. Cappelen et al. (2007, 2019); Almås et al. (2020). This approach implicitly assumes that each individual focuses on a single characteristic of the inputs when they decide about the fair distribution. In principle one could also assign multiple extended equity principles to each spectator. However, in that case, the question is qualitatively already answered by our regression analysis. The two different approaches should therefore be seen as complementary.

Consequentialism After the main regression has tested whether the spectators' distributive choices follow an extended equity principle, we also want to understand whether this extended equity principle is compatible with consequentialistic norms. For this purpose we compare the four cells of Scenario 1(i) with the four cells of Scenario 2 for each spectator. For each pair of cells, the completed tasks as well as the total payoff of the workers (consisting of their fixed payments plus the output that the spectators distribute) are the same. The difference is that the fixed payment is set to zero in Scenario 2 and the entire payoff is distributed by the spectator. This difference would not matter, if the distributive norms of the spectators were consequentialistic. They would distribute output in Scenarios 1(i) and 2 such that the overall payoff of each worker (fixed payment plus output share chosen by the spectator) would be the same in both scenarios. We can thus test whether the spectators are consequentialists by testing the equality of the workers' payoffs in the corresponding cells of Scenario 1(i) and 2.

We employ the Kolmogorov–Smirnov test for each of the four pairs of cells. The Kolmogorov–Smirnov test examines whether the payoffs chosen by the spectators in a given cell of Scenario 1(i) are equal to the payoffs chosen by the spectators in the corresponding cell of Scenario 2. More precisely, the Kolmogorov–Smirnov test checks whether the vertical distance between the cdfs of the two distributions of chosen payoffs is zero. We use the Kolmogorov–Smirnov test instead of a t-test or a Wilcoxon signed-rank test, because the equality of means or medians is not a sufficient criterion for determining whether the chosen payoffs are different between the two scenarios: if the more generous half of the spectators adjust their compensations upward (from Scenario 1(i) to 2) and the other half adjust theirs downward, then the median remains unchanged (a similar argument applies for the mean). The Kolmogorov–Smirnov test on the other hand is sensitive to such changes (although the Kolmogorov–Smirnov test is still invariant to permutations of the data). If the test rejects the null hypotheses, then the payoffs of the workers in the two scenarios are significantly different. In that case the spectators' distributive choices are incompatible with consequentialistic norms.

Note that we cannot dinstinguish whether a spectator follows a consequentialistic or non-consequentialistic norm if the spectator divides the output 50/50 in both scenarios. While a consequentialistic spectator that chooses 50/50 split in Scenario 1(i) will also choose a 50/50 split in Scenario 2, the same is true for a non-consequentialistic spectator. For this reason, we restrict the tests to those observations for which one can distinguish consequentialistic and non-consequentialistic norms. This means that we exclude spectators who choose a 50/50 split in both Scenario 1(i) and 2, when we perform the two tests mentioned above.

Freedom of Choice As a robustness check we test whether or not the effect of input characteristics on the distribution of output changes, if one allows for a choice of quantities by the workers. We do this by presenting to each pair of workers the fair distribution that a spectator had chosen in Scenario 1(i). We then ask the workers whether they want to complete 100 tasks or 200 tasks, given this fair distribution. There are four potential cases: both complete 100 tasks; the calculator completes 100 tasks and the ball-catcher completes 200 tasks; etc. In the next step we consider the following two cases: the calculator decides to complete 100 tasks and the ball-catcher chooses to complete either 100 tasks or 200 tasks. Presented with these two potential quantity choices, the same spectator as before decides again about the fair distribution of output between the workers. We increase the amount of money to distribute by \$10, so that spectators can change the relative distribution without disappointing workers' expectations. Consequently we compare compensation ratios before and after instead of absolute compensations (as in the test for consequentialism). If the deliberate choice of input quantities is of secondary importance for the spectators, the effect of the input characteristics on the fair compensations should remain unchanged.

To test whether the distributive decision is affected by the variation discussed above, we run regression (4.5) again, with the data from Scenario 3 and the corresponding two cells from Scenario 1(i). In addition we include interaction variables for Scenario 3 to test whether the coefficients differ between the two scenarios. When no dummy is significantly different from zero, this provides evidence for the fact that compensations are not affected by the ability to choose quantities. Note that these results should be interpreted with caution: First, the results only apply to our setting and it is well documented that in other settings questions of responsibility and free choice are decisive, see Cappelen et al. (2010); Konow (1996). In addition, the second distribution that spectators choose is constrained by the distribution they chose initially (as spectators are not allowed to reduce the absolute amount each worker receives).

4.5 Descriptive Statistics

Before we present our main result, this section presents descriptive statistics of the experiment.

Test subjects In total 301 people participated and 291 of them became spectators, whereas the other 10 became workers. Among the 291 spectators 49 did not answer the control questions correctly. The questions have been very simply and their sole purpose was to test whether the participants pay attention to the instructions. In order to focus on participants that paid attention, we exclude these 49 participants from our analysis. For the remaining 242 spectators the outcome of the experiment is described in the following paragraphs. Note that for Scenario 2 this number reduces to 121 because of a coding error in this scenario in the first runs of the experiment.

Assessment We asked spectators to assess the two tasks in the dimensions of relative tediousness, intellectually difficulty, toil and time required for completion. A scatterplot of these assessments by the spectators are given in Fig. 4.2.

The plots display the logarithms of the relative assessment of the two tasks, as they are used in our main regression. If a point is at the value $\ln 2 \approx 0.7$ of the 'lntedious-axis' in Fig. 4.2, for instance, then the corresponding spectator has stated that they assess the calculation-task as twice as tedious as the ball-task. In the opposite case (i.e., ball-tasks are assessed as twice as calculation-tasks) the point would be at $\ln 1/2 = -\ln 2 \approx -0.7$. As illustrated by Fig. 4.2, there is a lot of variation in how the spectators assess the tasks. This will help us to determine how the assessments of the spectators influence their distributive choices. It is worth pointing out, however, that there is a positive correlation between the different characteristics – see Table 4.1. In particular, the perception of the tasks in terms of tediousness and toil are very similar.

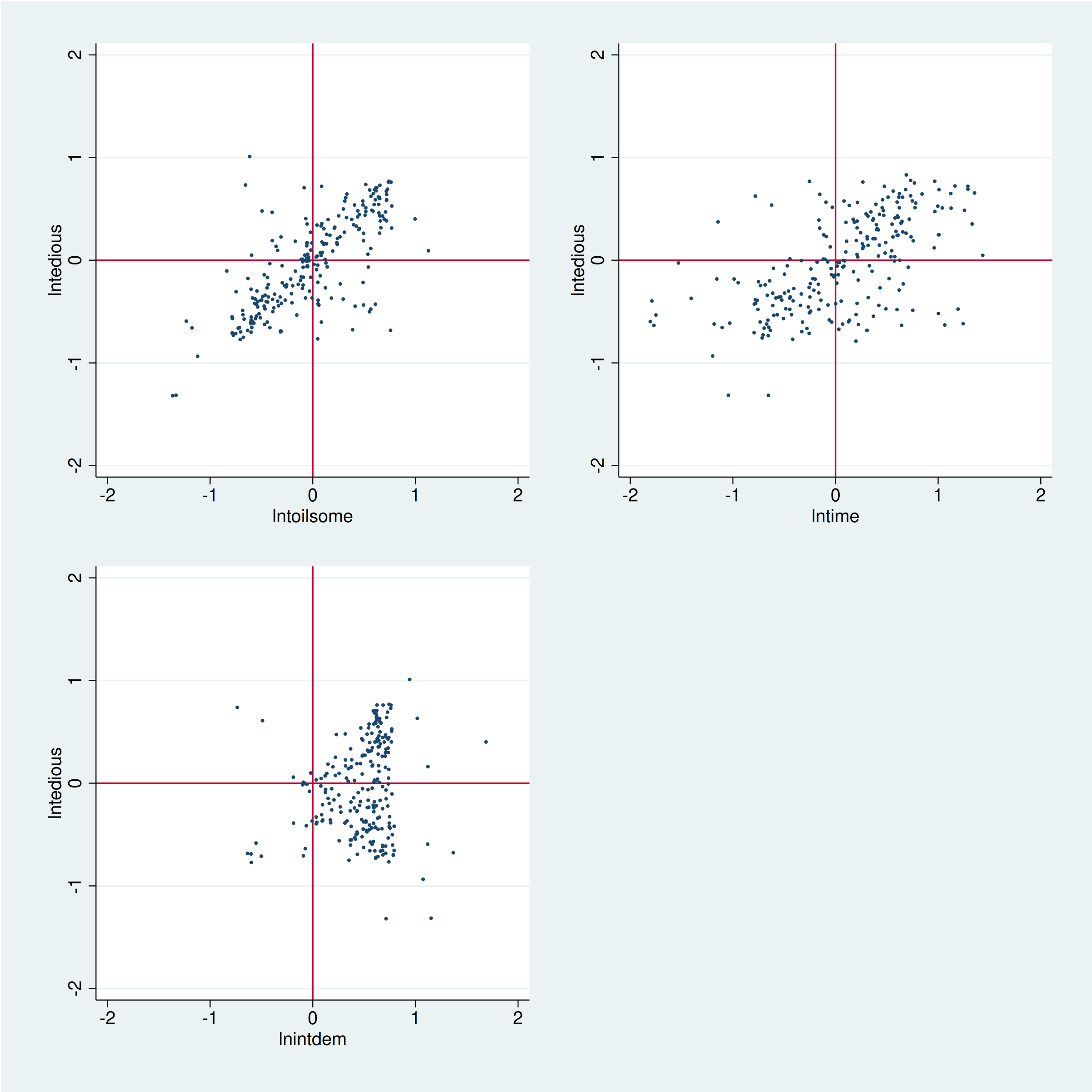


Figure 4.2: Log relative assessments.

Division of Money The histograms in Fig. 4.3 display the output distributions chosen by the spectators in the Scenarios 1(i) and (ii) and 5 (descriptive statistics for Scenarios 2 to 4 are postponed to Section 4.6; histograms for all scenarios can be found in Appendix 4.C). The abscissa in each histogram represents the share of the output given to the first worker, who always performs the calculation-tasks (e.g., the bar in the middle denotes the share of spectators choosing a 50%/50%-distribution). There are twelve histograms corresponding to the twelve cells appearing in Scenarios 1(i), (ii) and 5, as indicated by the subtitles. As illustrated by the first two rows, there is significant variation in how the different spectators distribute the output between the workers, if these workers perform heterogeneous tasks (i.e., in Scenarios 1(i) and (ii)). The peaks in the histograms are at shares that are relatively simple ratios like 1/4, 1/3, etc. There is much less variation in

Table 4.1: Correlations for log relative assessments

	lntedious	lntoilsome	lntime	lnintdem
lntedious	1			
lntoilsome	0.738***	1		
lntime	0.563***	0.549***	1	
lnintdem	0.127*	0.174**	0.206**	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

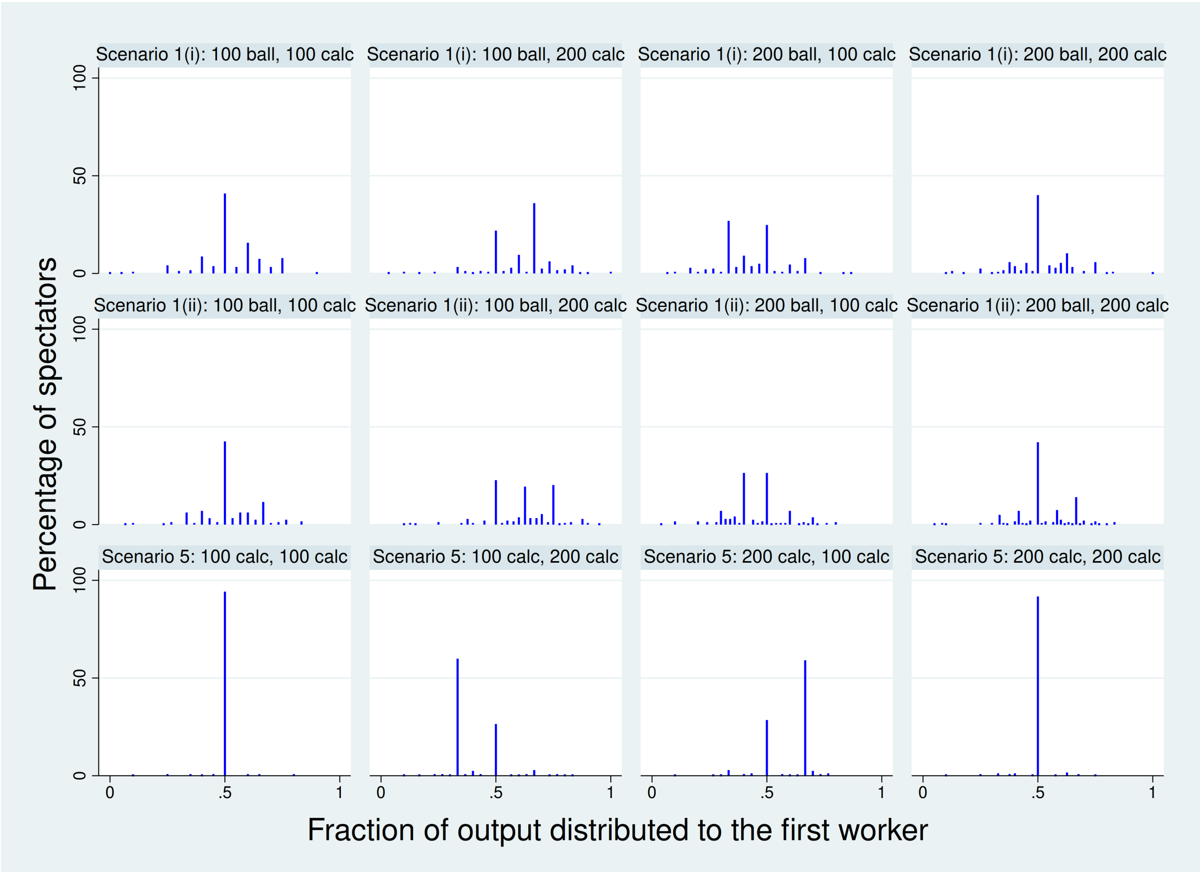


Figure 4.3: Distribution of output in Scenarios 1 and 5.

Scenario 5 (see the last row in Fig. 4.3) in which both workers perform the same task. In this scenario, the spectators only deviate from an equal split of the payoff in the two cells in which one worker performs twice as many calculation-tasks as the other one. In line with the equity principle, most spectators chose the split 2/3 to 1/3 in these cells.

Questionaire While the complete statistics are given in Appendix 4.C, we only briefly comment on selected findings here. First of all, the participants approved of the experimental design: the vast majority of the participants perceived the experiment as neither biased (96%) nor confusing (91%). Second, there was some variation in the demographics and the socio-economic status of the participants: 36% of the subjects are female, 49%

were born after 1984, 56% hold at least a bachelor degree and 52% earned at least $35,000 in net labor income last year.

4.6 Results

In this section we show the results of the regression analysis and the classification of the spectators (in terms of the input characteristics that dominate their distributive choices). The main part of the paper only discusses the regression with logarithmic variables described in (4.5). The results of the regression with dummies described in (4.7) are reported in Appendix 4.A. Finally, we present the outcome of the test of consequentialism and the impact of free choice. As already explained in Section 4.5, we restrict the analysis to those individuals that answered all control questions correctly.

Regression Results Table 4.2 collects the regression results corresponding to the logarithmic equation (4.5) and variations thereof. The dependent variable in all variations is lncomp, i.e., the logarithm of the relative compensations (calculation-tasks relative to ball-tasks) chosen by the spectators. The explanatory variables are lnprod, lntedious, etc., which have been introduced in Section 4.4 and which denote the logarithms of the ratio of input characteristics: productivity, assessed tediousness, etc. To compute the regressions in Table 4.2, the spectators' choices in the Scenarios 1(i), (ii) and 5 are used, which add up to $242 \times 12 = 2904$ observations. In column *+Sc4* we also use the data from Scenario 4, so that the number of observation is $242 \times 16 = 3872$. We focus on Scenarios 1, 4 and 5, because the scenarios are identical apart from variations in parameters that are represented by explanatory variables in the regression. Scenarios 2 and 3 differ from the other scenarios in aspects that are not captured by the regression. The data from these scenarios will be used for testing consequentialism and the impact of free choice.

The result of our baseline regression described in (4.5) is stated in the column *base*. The mixed model we estimate distinguishes between the average coefficient of an explanatory variable (listed at the top of the table) and the variation of the coefficient across the different spectators (given by the standard deviations sd(lnprod), sd(lnquant), etc. listed at the bottom of the table). Take 'quantity' as an example: the coefficient 0.56 of lnquant means that an increase in the relative quantity by 1% leads to an average increase in the relative compensation by 0.56%; the standard deviation of this proportional factor across the various spectators is 0.36. By and large we find support for Hypothesis 1, as shown in column *base*:

a) Quantity has a statistically significant and positive impact on the relative compensation.

Table 4.2: Regressions with log regressors

	ols	base	$<$ ba	$\geq$ 35k	tedious	toil	+Sc4	time
Constant	0.02	0.00	-0.04	0.01	-0.00	-0.00	-0.00	-0.00
lnprod	-0.07*	-0.05*	-0.04	-0.13***	-0.05	-0.05	-0.03	-0.05*
lnquant	0.56***	0.56***	0.56***	0.56***	0.56***	0.56***	0.53***	0.56***
lntedious	0.20***	0.16**	0.16**	0.16**	0.50***			
lntoilsome	0.09	0.05	0.05	0.05		0.43***	0.35***	
lntime	0.30***	0.28***	0.29***	0.28***				0.38***
lnintdem	0.08	0.16**	0.23***	0.03	0.21***	0.20***	0.21***	0.14**
yes			0.08*	-0.01				
yes $\times$ lnprod			-0.02	0.15**				
yes $\times$ lnintdem			-0.16	0.24**				
pos toilchange							0.29***	
sd(lnprod)		0.09	0.09	0.07	0.11**	0.10*	0.17***	0.09*
sd(lnquant)		0.36	0.36***	0.36	0.36***	0.36***	0.33***	0.36***
sd(lntedious)		0.00	0.10	0.00	0.52			
sd(lntoilsome)		0.00	0.00	0.00		0.41*	0.29**	
sd(lntime)		0.37	0.37**	0.39				0.40***
sd(lnintdem)		0.35	0.34*	0.33	0.48**	0.57***	0.57***	0.35***
sd(Constant)		0.20	0.20***	0.20	0.20***	0.20***	0.21***	0.20***
sd(Residual)		0.35	0.35***	0.35	0.35***	0.35***	0.40***	0.35***
N	2904	2904	2904	2904	2904	2904	3872	2904

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, s.e. clustered at individual level,
for *base* and $\geq$ *35k*, significance of sd($\cdot$) was not computable

b) Tediousness, time required and intellectual difficulty of an input have a statistically significant and positive impact on the relative compensation. We do not find a significant influence of toil in our baseline regression. In terms of effect size, the most important determinants of the fair compensations are (in decreasing order): quantity, time, tediousness and intellectual difficulty. The coefficients differ not only in their effect size, but also by how much they vary across spectators. As stated in the lower third of the regression table, the spectator-specific components of the coefficients for productivity, time, and intellectual difficulty exhibit a large standard deviation relative to the average coefficient. This means that the spectators disagree about the importance of these characteristics. In contrast, the spectators agree about the impact that the tediousness of inputs should have on the fair distribution.

c) Productivity has a negative effect, but the coefficient is comparably small and it is only significant at the 5%-level. The constant has no effect at all on the fair compensation.

The results of the mixed model are also consistent with a standard ordinary least squares regression that is reported in column *ols* as a reference.

Given the apparent disagreement of the spectators concerning the relevance of some characteristics, we want to study whether the weights assigned to the various characteristics depend on the socioeconomic status of the spectators – measured in terms of education and yearly income. For this purpose we run two additional regressions in which we interact productivity and intellectual difficulty (which are the characteristics with the largest variation relative to the average coefficient) with two dummies: first, a dummy for spectators that do not have a bachelor degree; and second, a dummy for spectators whose yearly net labor income is above $35k.

Studying the effect of education (column "$<$ *ba*"), one finds that spectators with a bachelor degree assign a higher weight to the intellectual difficulty of an input as the population at large: the coefficient for "lnintdem" (which describes the effect for spectators with a bachelor degree) increases relative to the baseline regression. The interaction term "yes $\times$ lnintedem" (which describes the differential effect for spectators with lower education) is negative but not significant (the "yes"-row describes the differences in levels of compensations between those with and without a bachelor degree). Concerning productivity, in contrast, the two educational groups do not really differ and productivity has no significant effect in both groups. In a next step we distinguish spectators by their yearly income (column "$\geq$ *35k*"). We find that spectators with higher incomes want to compensate considerably more for productivity and intellectual difficulty (the coefficients "yes $\times$ lnprod" and "yes $\times$ lnintdem" are significantly positive) than spectators with lower incomes (the coefficients "lnprod" and "lnintdem" are insignificant or even negative). As one can see by comparing the interaction terms across the columns "$<$ *ba*" and "$\geq$ *35k*", the disagreement between individuals with different incomes is much stronger than the disagreement between individuals with different educational levels. While we can only speculate about the reasons for the heterogeneity due to income and education, the focus on productivity and intellectual difficulty among those groups is consistent with the self-serving morals documented by Gino et al. (2013) and Diekmann (1997), among others.

As shown in Table 4.1, some variables in the regression (lntedious, lntoilsome, lntime) are strongly correlated. At the same time, their coefficients are not very large. It thus might be possible that our analysis splits up one large effect in three small effects. In order to test this, we run three additional regressions in which we include only one of these three variables respectively. The results in columns *tedious*, *toil* and *time* support our expectation: if the regression contains only of the three variables, its coefficient increases strongly relative to the baseline case, as it partly captures the effect of the other two related characteristics. Instead of arguing that, e.g., tediousness is the "primary characteristic" among the three and disregarding the other two, we favor the following interpretation: all three characteristics serve as proxies that (partly) capture a more abstract concept which can be understood as the *burden of input provision*. In line with this interpretation we provide a factor analysis in Appendix 4.B as an alternative way to deal with the correlations between *tedious*, *toil* and *time*. However, because the interpretation of the factors extracted by a factor analysis is not obvious, we focus on the analysis provided above in the main text.

In a last step of the regression analysis we check whether input characteristics drive the distributive choices and not the other way around. Remember that in Scenario 4 spectators are informed about the workers' perception that the calculation-task is twice as toilsome as the ball-task. Given that all but two spectators assess the calculation-task as less than twice as toilsome, this implies an upward shift in the perceived relative toil. In order to test whether this exogenous variation affects the fair compensation, we include Scenario 4 in our regression analysis and add a dummy for this scenario ('pos toilchange'). To focus on the change in lntoilsome, we exclude the highly correlated variables lntedious and lntime from the analysis. The result of this regression is presented in column *+Sc4* of Table 4.2. The coefficient of 'pos toilchange' is indeed significant, which confirms that toil has a direct effect on the fair distribution. In addition the positive sign of the coefficient confirms that the spectators compensate more for toilsome inputs: the relative increase of the perceived toil of the calculation-task leads to an increase of the relative compensation of the calculator.

Classification of Spectators The regression analysis provides estimates of, first, the average effect of input characteristics on distributive choices, and second, the variation of this effect across the different spectators. As an alternative approach one can consider each spectator separately and determine which input characteristic dominates their choice. This can be done by minimizing a loss function as described in Eq. (4.6) in Section 4.4. For each spectator and each input characteristic, the loss function sums up the deviations of the spectator's choices from the choices that they would make, if they followed an extended equity principle in which only this characteristic matters. As described in Section 4.4, *equality* and the standard *equity* principle can also be treated as special cases of the extended equity principle.

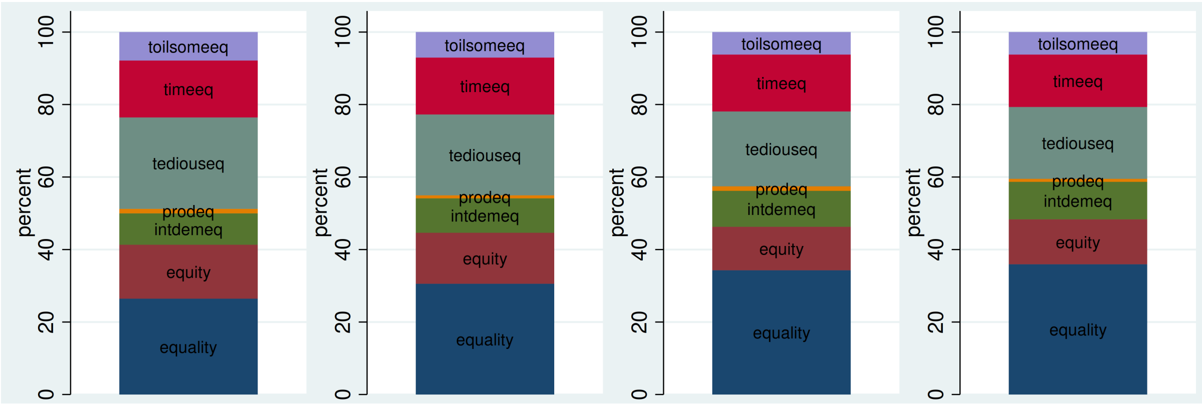


Figure 4.4: Dominant input characteristic for a loss function with $p = 1/2/3/4$.

The result of this classification is displayed in Fig. 4.4 for different values of the exponent p. In this figure *timeeq* denotes the fraction of spectators following an extended equity principle which weighs quantities by time only – and analogously for *tediouseq*, etc. Comparing the four cases one can see that the classification depends on p only weakly.[17] By and large Fig. 4.4 provides support for Hypothesis 2:

a) More than 50% of spectators follow an extended equity principle that weighs quantities by either intellectual difficulty, tediousness, toil or time. The prevalence of these characteristics is, in decreasing order: tediousness, time, intellectual difficulty and toil.

b) Less than 1.3% of spectators (3 out of 242) weigh quantities by productivity.

The classification of the spectators is thus also consistent with the results of the regression analysis. However, the classification reveals two aspect that are not apparent from the regression analysis. First, 12–15% of all spectators follow the standard equity principle

[17] In addition to varying p we also test robustness by using the relative compensation and the compensation share of the calculator (instead of the log of the relative compensation) in the loss function. However, the results are very similar to those shown in Fig. 4.4.

Note that this approach does not allow for a natural goodness of fit analysis: per construction everyone gets assigned one extended equity principle, without taking the distance to the second closest equity principle into account. In particular this is worth mentioning for the highly correlated characteristics *time*, *tedious* and *toilsome*: the assignment to these subgroups are likely to switch for small variations in the compensations. It could thus be preferable to interpret these three groups as one. This relates to the interpretation of the three characteristics *time*, *tedious* and *toilsome* as proxies for the burden of factor provision, as discussed above.

which considers only unweighted quantities. These spectators might weigh quantities by input characteristics that are not captured by our study. Second, 26–36% of the spectators divide output equally between the workers, independent of the quantities or their assessment of the inputs. The high percentage of spectators that divide equally might appear surprising, but is in line with previous experimental studies – see e.g. Cappelen et al. (2007). As for the regression analysis, we provide a factor analysis in Appendix 4.B as an alternative way to deal with the correlations between *tedious*, *toil* and *time*.

Consequentialism As explained in Sections 4.3 and 4.4, Scenarios 1(i) and 2 have been designed such that the total payoff of each worker (i.e., fixed payment plus the money assigned by the spectator) should be the same across both scenarios, if the spectators were following a consequentialistic norm. The scatterplots in Fig. 4.5 display the total payoffs of the calculators as chosen by the spectators – with one scatterplot for each combination of quantities in Scenario 1(i) and 2.[18]

For each point, the position on the y-axis represents the choice of a spectator in Scenario 1(i) ("\$10 fixed pay") and the position on the x-axis represents the choice of the same spectator in Scenario 2 ("\$0 fixed pay"). If the spectators were consequentialists, the points should lie on the 45 degree line (which means that the total payoffs are the same in both scenarios). The scatterplots and the fitted trends in Fig. 4.5 suggest that the distributions chosen by the spectators systematically deviate from the 45 degree line: the presence of a fixed payment leads to a compression of the distribution of total payoffs, which corresponds geometrically to a clockwise rotation of the 45 degree line around the center.

This systematic deviation is consistent with an extended equity principle. Consider a spectator who gives a share α of the output in Scenario 2 ($\alpha \cdot output_2$) to the calculator. If this spectator follows an extended equity principle, they should also give a share α of output in Scenario 1(i) ($\alpha \cdot output_{1(i)}$) to the calculator. This implies for the total payoff of the calculator: it is equal to $\alpha \cdot output_2$ in Scenario 2, in which the fixed payment is \$0; and it is equal to $10 + \alpha \cdot output_{1(i)} = 10 + \alpha \cdot (output_2 - 2 \cdot 10)$ in Scenario 1(i), because the fixed payment is \$10 and $output_{1(i)} = output_2 - 2 \cdot 10$. The total payoff of the calculator in Scenario 1(i) is larger than in Scenario 2 (i.e. a dot in the scatterplot is above the 45 degree line), if $10 + \alpha \cdot (output_2 - 2 \cdot 10) > \alpha \cdot output_2 \Leftrightarrow \alpha < 1/2$. Analogously, the payoff in Scenario 1(i) is smaller and a dot in the scatterplot is below the 45 degree line, if

[18] As explained above, the purpose of the test for consequentialism is to understand whether the non-trivial distributive choices observed in the experiment can be explained by consequentialistic norms of the spectators. The test for consequentialism thus focuses on spectators with non-trivial choices, which means spectators who have chosen an unequal split in either Scenario 1(i) or 2. The number N below each graph states how many spectators, who answered all control questions correctly, chose an unequal split.

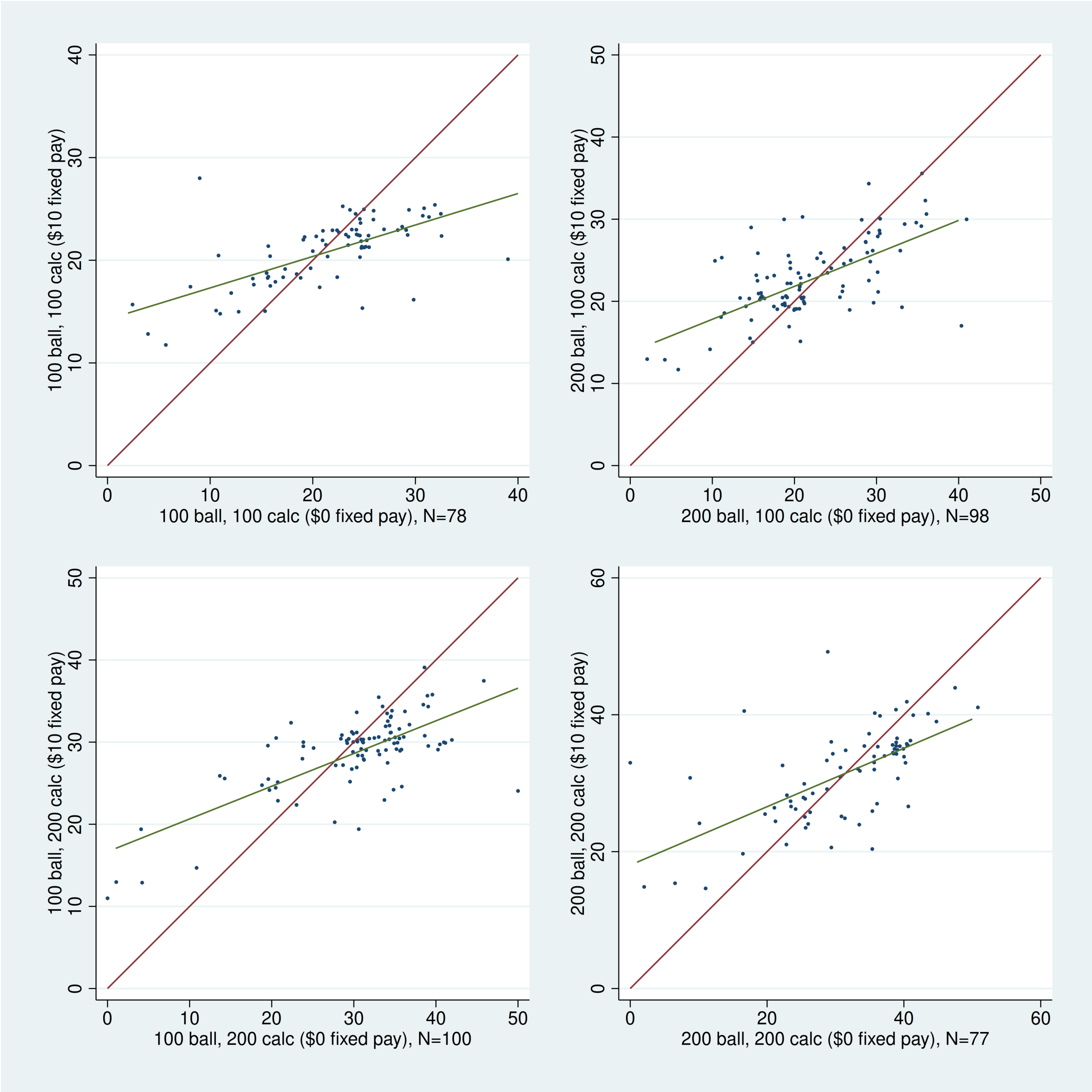


Figure 4.5: Total payoffs for the calculator in Scenarios 1(i) and 2.

$\alpha > 1/2$. Graphically, the spectators with $\alpha < 1/2$ are in the left half of each scatterplot and vice versa. An increase in total payoffs for the calculator in case of $\alpha < 1/2$ and a decrease in case of $\alpha > 1/2$ thus corresponds to a clockwise rotation of the 45 degree line around the center. This is in line with the pattern displayed in Fig. 4.5 where the green linear fits are flatter than the red 45 degree lines.

Beyond the qualitative discussion of the scatterplots, we also examine formally whether spectators are consequentialists. We use the Kolmogorov-Smirnov test, which tests whether the payoffs chosen by the spectators in a given cell of Scenario 1(i) are equal to the payoffs chosen by the spectators in the corresponding cell of Scenario 2. More precisely, the Kolmogorov-Smirnov test checks whether the vertical distance between the cdfs of two distributions is zero. If the test rejects the null hypotheses, then the payoffs of the workers in the two scenarios are significantly different. In that case the spectators' distributive choices are incompatible with consequentialistic norms.

Table 4.3: Kolmogorov-Smirnov test for consequentialism

	100ball100calc	200ball100calc	100ball200calc	200ball200calc
p-value	0.0000	0.0095	0.0000	0.0014
N	78	98	100	77

The results of the Kolmogorov-Smirnov test are stated in Table 4.3. The Kolmogorov-Smirnov test shows that we can reject with 1% significance that the distributions of payoffs in the two scenarios are the same. This means that the spectators' choices of a fair distribution are incompatible with a welfarist or, more generally, a consequentialistic norm. The result of the Kolmogorov-Smirnov test is therefore consistent with our Hypothesis 3.

Freedom of Choice As a last step we test whether the spectators' choices of fair distributions change systematically, if the input quantities are freely chosen by the workers. For this purpose, Scenario 1(i) and 3 have been designed such that the inputs of the workers are the same, but in Scenario 3 the spectators distribute the output after they have learned that the quantities were freely chosen by the workers. As explained in Section 4.4, we increase the amount of money to distribute in Scenario 3 by \$10 to allow spectators to choose a different relative compensation without reducing the absolute compensation of any worker. Analogously to the previous paragraph, the scatterplots in Fig. 4.6 display the compensation shares of the calculator that result from the spectators' choices – with one scatterplot for each of the two cases studied in Scenario 1(i) and 3.

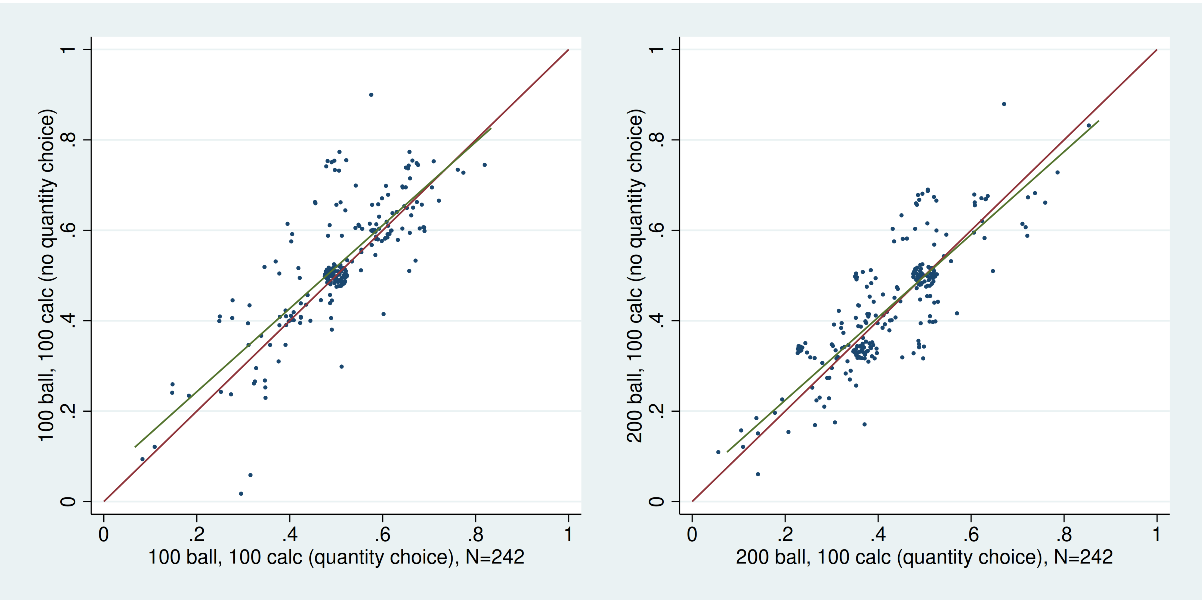


Figure 4.6: Compensation share the calculator receives in Scenarios 1(i) and 3.

For each point, the position on the y-axis represents the choice of a spectator in Scenario 1(i) ("no quantity choice") and the position on the x-axis represents the choice of the same spectator in Scenario 3 ("quantity choice"). If spectators do not change their division of money the points should thus lie on the 45 degree line. The scatterplots and the fitted trends in Figure 4.6 indicate that the distributions chosen by the spectators are somewhat affected by this variation, but not in a systematic way. Some spectators give a larger share to the calculator in Scenario 3 than in Scenario 1(i) (so that the points are to the right of the 45 degree line). And some spectators give a smaller share to the calculator in Scenario 3 than in Scenario 1(i) (so that the points are to the left of the 45 degree line). This holds for both cases depicted in Fig. 4.6: First, if both workers choose a low quantity, and second, if the ball-catcher decides to complete more tasks than the calculator.

To investigate whether our main result (the impact of input characteristics on the fair distribution) is robust to the inclusion of a quantity choice, we study a variant of regression (4.5): using the data from Scenario 3 and the corresponding two cells from Scenario 1(i) in our regression, we include interaction variables for Scenario 3 in order to test whether the coefficients differ between the two scenarios. We present the result of this regression in Table 4.4.

Table 4.4: Regressions for Scenarios 1(i) and 3

	Sc1+Sc3	
Constant	0.05	(0.07)
lnquant	0.55***	(0.06)
lntedious	0.17	(0.10)
lntoilsome	0.12	(0.09)
lntime	0.33***	(0.06)
lnintdem	0.04	(0.11)
number of scenario=3	-0.04	(0.04)
number of scenario=3 × lnquant	-0.07	(0.05)
number of scenario=3 × lntedious	-0.07	(0.07)
number of scenario=3 × lntoilsome	0.05	(0.07)
number of scenario=3 × lntime	-0.02	(0.04)
number of scenario=3 × lnintdem	-0.06	(0.06)
N	968	

S.e. in parentheses and clustered at individual level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.4 shows that none of the interaction coefficients (*number of scenario=3 × ...*) is statistically significant. This means that spectators do not systematically change their distributive decisions when workers can choose the number of tasks they want to complete. This is consistent with our Hypothesis 4. As already mentioned in Section

4.4, these results should be interpreted with caution, as the choice set of spectators in Scenario 3 is restricted by their choice made in Scenario 1(i).[19]

4.7 Concluding Remarks

This paper studies the fair division of money in an online experiment with heterogeneous labor inputs. We document that impartial spectators at large reward labor according to the number of completed tasks as well as the assessed relative tediousness, toil and time required for completion. Productivity and the intellectual difficulty of a task is only valued by those with a high level of education or a high income. We propose an extended equity principle as a potential theoretical underpinning for the observed fair divisions. In addition we show that the behavior of spectators is inconsistent with consequentialists theories of distributive justice.

Our analysis offers an explanation for why people perceive 'disproportionate wages' as unfair, as exemplified by the quotes in the introduction. Although it might not be feasible to calculate the exact fair wages according to the extended equity principle in each case, people are able to notice strong deviations from the fair wage ratio. This means with respect to the quotes cited in the introduction: if people regard the physical and psychological burden of providing a labor input as the most relevant dimension for compensation and if they do not think that the burden of providing management work is six hundred times as high as providing nursing work, they will deem a relative compensation of six hundred to one as unfair.

This paper has studied the fair distribution of output among a certain set of inputs. The experimental approach of the paper, however, is more general and can easily be adjusted in order to study fair compensations for other types of heterogeneous inputs. A particular interesting objective of future studies would be to investigate the fair distribution of output between capital and labor inputs.

[19]For 18% of all spectators this restriction was binding, i.e., 18% of spectators gave all of the additional money to only one of the two workers.

4.A Appendix: Dummy Regression

The main regression in Eq. (4.5) uses the continuous assessment provided by the spectators. It might be the case, however, that some spectators can only rank the tasks along the various dimensions. They might be able to say that task x is more tedious than y, but they might not be able to specify by how much the tasks differ with respect to their tediousness. In order to address this concern, we also estimate a second regression in which the continuous ratios are replaced by two dummies:

$$\begin{aligned}\ln comp_{ic} = {} & \beta_{0i} + \beta_{1i}\mathbb{1}\{\ln quant_c > 0\} + \beta_{2i}\mathbb{1}\{\ln quant_c < 0\} + \beta_{3i}\mathbb{1}\{\ln prod_c < 0\} \\ & + \beta_{4i}\mathbb{1}\{\ln tedious_{ic} > 0\} + \beta_{5i}\mathbb{1}\{\ln tedious_{ic} < 0\} \\ & + \beta_{6i}\mathbb{1}\{\ln intdem_{ic} > 0\} + \beta_{7i}\mathbb{1}\{\ln intdem_{ic} < 0\} \\ & + \beta_{8i}\mathbb{1}\{\ln toilsome_{ic} > 0\} + \beta_{9i}\mathbb{1}\{\ln toilsome_{ic} < 0\} \\ & + \beta_{10i}\mathbb{1}\{\ln time_{ic} > 0\} + \beta_{11i}\mathbb{1}\{\ln time_{ic} < 0\} + \varepsilon_{ic} \end{aligned} \tag{4.7}$$

where $\mathbb{1}\{\cdot\}$ denotes the indicator function. For each characteristic of the inputs, there are two dummies: the first is equal to one if and only if the calculation-tasks are strictly more *tedious/intdem/...* than the ball-tasks, while the second is equal to one in the opposite case. For productivity there is only one dummy, because there is only a scenario in which ball-tasks are more productive than calculation-tasks, but not vice versa. As for the standard regression (4.5), the dependent variable is ln comp.

Table 4.5 collects the regression results corresponding to the Eq. (4.7) and variations thereof. The dummy variable 'C tedious', for instance, corresponds to $\mathbb{1}\{\ln tedious_{ic} > 0\}$ in the notation from Eq. (4.7). The meaning of 'C tedious' = 0.20 in the baseline regression is then: "if c.p. the tediousness of calculation-tasks is strictly higher than the tediousness of calculation-tasks, then the relative compensation for calculation-tasks increases by $e^{0.2} - 1 \approx 22\%$". For the analysis of the dummy regressions we are not interested in the coefficients for B and C per se, but in the difference between the two (that is, we are interested in C tedious – B tedious). For this reason we provide the p-values for the statistical significance for these differences at the bottom of the regression table. The p-value of the t-test testing for C quant – B quant = 0, for instance, is given in the row 'p_quant'.

Considering the same variations as in case of the logarithmic regressions presented in the main part of this paper, the results are very similar. The same input characteristics have a significant impact on the fair distribution as in case of the logarithmic regression – with two differences: in the baseline regression, intellectual difficulty is no longer statistically significant, whereas toil is already significant in the baseline regression.

Table 4.5: Regressions with dummy regressors

	ols	base	< ba	≥ 35k	tedious	toil	+Sc4	time
Constant	-0.02	-0.01	-0.04	-0.01	-0.02	-0.01	-0.01	-0.01
B prod	0.03	0.03	0.03	0.08***	0.03	0.03	0.02	0.03
C quant	0.41***	0.41***	0.41***	0.41***	0.41***	0.41***	0.37***	0.41***
B quant	-0.37***	-0.37***	-0.37***	-0.37***	-0.37***	-0.37***	-0.36***	-0.37***
C tedious	0.21**	0.20**	0.20**	0.22***	0.28***			
B tedious	-0.01	0.01	0.01	0.02	-0.20***			
C toilsome	-0.02	-0.03	-0.03	-0.03		0.12*	0.10	
B toilsome	-0.21**	-0.19**	-0.17**	-0.18**		-0.34***	-0.27***	
C time	0.23*	0.21***	0.22***	0.20***				0.29***
B time	-0.04	-0.06	-0.09	-0.07				-0.19**
C intdem	0.01	0.01	0.03	-0.06	0.07	0.20***	0.19***	0.01
B intdem	-0.21	-0.12	-0.63	0.05	-0.03	0.07	-0.05	-0.22
yes			0.06*	-0.00				
yes × B prod=1			-0.00	-0.09**				
yes × C intdem=1			-0.05	0.10*				
yes × B intdem=1			0.61	-0.37				
pos toilchange							0.28***	
sd(B prod)		0.04	0.03	0.01	0.06*	0.07**	0.10***	0.03
sd(C quant)		0.32	0.31	0.32	0.32***	0.32***	0.27***	0.31***
sd(B quant)		0.26	0.25	0.26	0.25***	0.26***	0.24***	0.26***
sd(C tedious)		0.30	0.29	0.30	0.30***			
sd(B tedious)		0.24	0.24	0.24	0.43***			
sd(C toilsome)		0.00	0.00	0.00		0.19***	0.12	
sd(B toilsome)		0.24	0.20	0.23		0.39***	0.33	
sd(C time)		0.00	0.04	0.04				0.00
sd(B time)		0.26	0.28	0.26				0.35***
sd(C intdem)		0.00	0.00	0.00	0.06	0.25***	0.30*	0.29***
sd(B intdem)		0.08	0.00	0.00	0.00*	0.00	0.00	0.42***
sd(Constant)		0.13	0.12	0.13	0.14***	0.14***	0.14**	0.14***
sd(Residual)		0.35	0.35	0.35	0.35***	0.35***	0.40***	0.35***
p_quant	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
p_tedious	0.000	0.001	0.002	0.001	0.000			
p_toilsome	0.001	0.007	0.015	0.006		0.000	0.000	
p_time	0.000	0.000	0.000	0.000				0.000
p_intdem	0.221	0.323	0.083	0.270	0.311	0.195	0.002	0.153
N	2904	2904	2904	2904	2904	2904	3872	2904

S.e. clustered at individual level; for *base*, < *ba*, ≥ *35k*, significance of sd(·) was not computable

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.B Appendix: Factor Analysis

In Section 4.5 we documented a high correlation between *tedious*, *toil* and *time*. Consistent with this, we favor the interpretation of *tedious*, *toil* and *time* as proxies for the *burden of input provision*, as discussed in Section 4.6. The regression analysis has shown that the effect size and statistical significance of the three variables increases considerably when one includes only one of these variables at a time. Similarly, for the classification of spectators via a loss function, we suggested to treat spectators following *tedious*-, *toil*- or *time*-extended equity principles as a single group.

In this appendix we present a factor analysis for the variables *tedious*, *toil*, *time* and *intdem* as an alternative approach to reduce the number of characteristics. More precisely, we first compute the loading matrix (represented by the left graph in Figure 4.7) and an orthogonal rotation that simplifies the interpretation (the right graph in Figure 4.7). The figure suggests the interpretation of Factor 2 as intellectual difficulty and Factor 1 as the burden of factor provision.

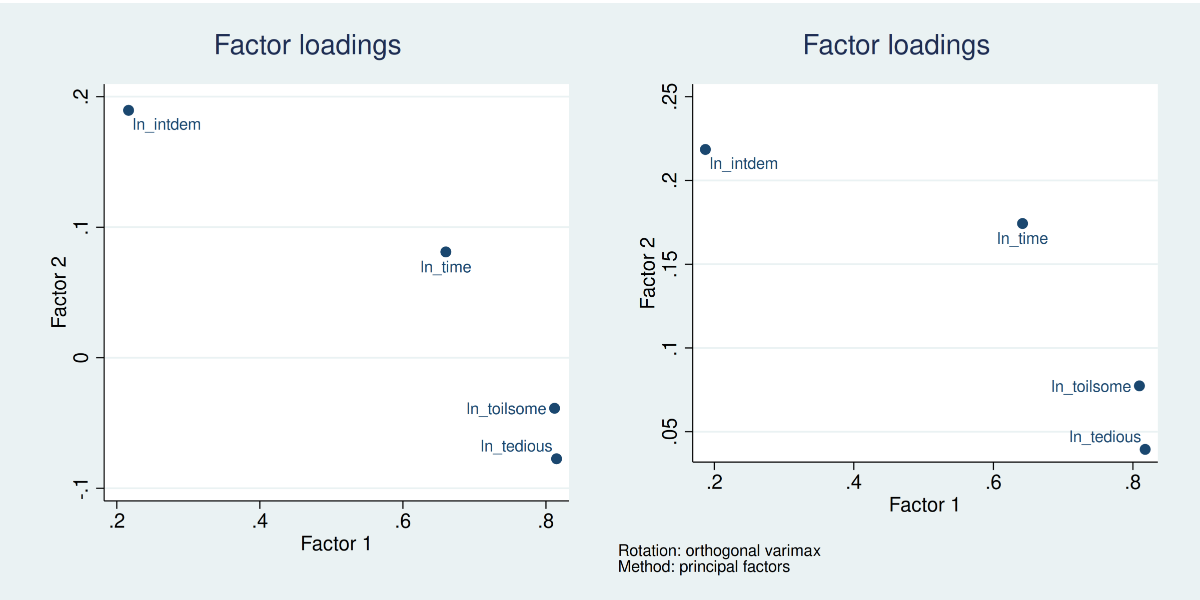


Figure 4.7: Unrotated and rotated factor loadings for two factors

When we repeat the baseline regression analysis with the these two factors instead of *tedious*, *toil*, *time* and *intdem*, we find very similar results – as presented in Table 4.6. Both factors have a statistically significant, positive impact on the distributive choices of the spectators (with Factor 1 (“burden of input provision”) being more significant than Factor 2). However, it is not directly clear how to interpret the effect sizes of the factors.

Analogously, we repeat the classification of spectators by means of a loss function and adjust the equity principle for the first and second factor, respectively. The result presented in Figure 4.8 is similar to the one with disaggregated characteristics: the frac-

Table 4.6: Regressions with factor variables

	lncomp	
Constant	0.02	(0.01)
lnprod	-0.08***	(0.02)
lnquant	0.56***	(0.03)
lnfactor1	0.29***	(0.04)
lnfactor2	0.25*	(0.12)
sd(lnprod)	0.00	(0.00)
sd(lnquant)	0.36***	(0.02)
sd(lnfactor1)	0.38***	(0.06)
sd(lnfactor2)	0.76	(0.16)
sd(Constant)	0.18***	(0.06)
sd(Residual)	0.35***	(0.03)
N	2904	

Standard errors in parentheses
S.e. clustered at individual level
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

tion of spectators following a productivity-extended equity principle is negligible, while roughly half of all spectators follow standard equity or equality and the other half follows a "factor"-extended equity principle.

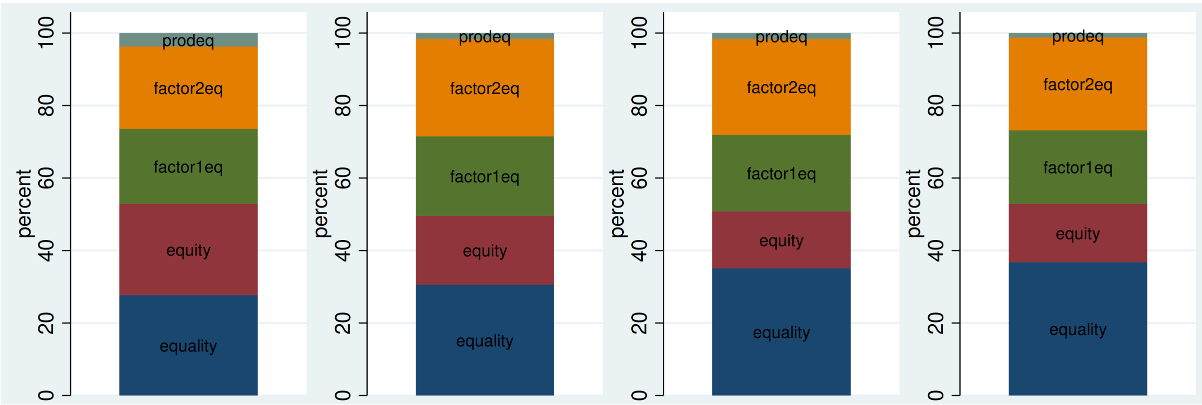


Figure 4.8: Dominant input characteristic for a loss function with $p = 1/2/3/4$.

4.C Appendix: Additional Tables and Graphs

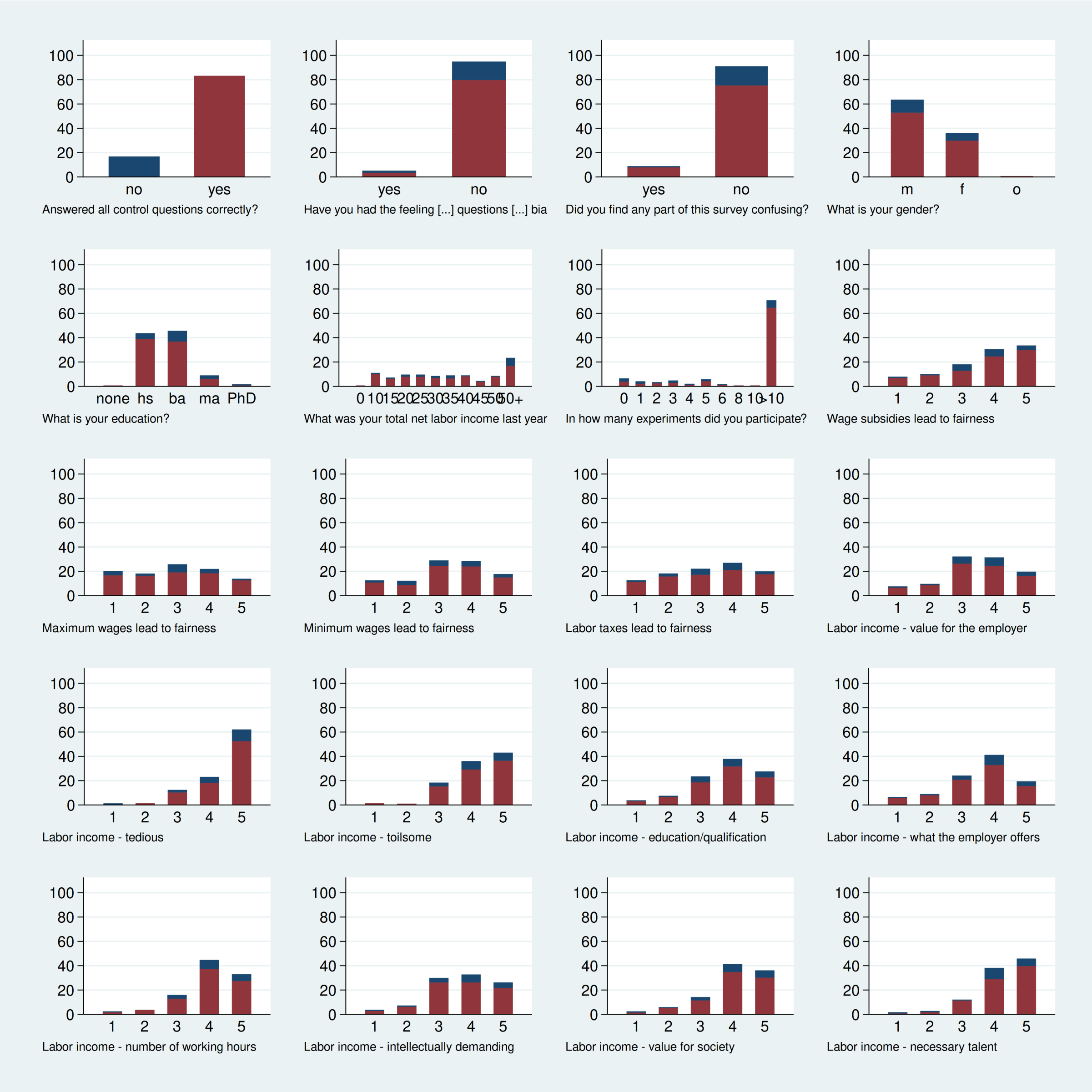


Figure 4.9: Complete questionnaire (in red: subjects that answered all control questions correctly; 5-point Likert scale: 1=do not agree at all, 5=fully agree).

Figure 4.10: Distribution of output in all scenarios.

4.D Appendix: Experimental Instructions

You are being invited to take part in a research study.

Purpose of the research:

We are studying the perception of people about the **fair** distribution of money in different settings.

Study Procedures:

You will be asked to answer questions on a short online survey. Your total expected time commitment for this study is **roughly 30 minutes.** There are no right or wrong answers, but there are a few **control questions** that will reveal whether you are reading the instructions and the questions properly. If the answers to the control questions show that your are not paying attention, we reserve the right to withhold your payment. For our research it is very important that you answer honestly and read the questions very carefully before answering.

Compensation:

If your responses were not flagged (see previous paragraph) and you completed the survey in full, you will receive a **compensation of $5** transferred to your mTurk account after three days.

Confidentiality:

All records from this study will be kept confidential. Your responses will be kept private, and we will not include any information that will make it possible to identify you in any report we might publish. Research records will be stored securely on password-protected computers. The research team will be the only party that will have access to your data.

Whom to contact with questions:

1. Marius Vogel, University of Cologne, marius.vogel@wiso.uni-koeln.de

2. Dr. Dr. Raphael Flore, University of Cologne, flore@wiso.uni-koeln.de

Confirmation of Consent:

I understand the information that was presented.
I certify to participate in this survey once only.
I hereby give my consent to be the subject of your research.

Preliminary Information

Please insert your MTurk ID in the following.

Next

1 Instructions

The participants of this experiments are divided into two groups with pre-specified roles: Members of Group 1 will complete different tasks, while members of Group 2 will divide money between members of Group 1.

You were assigned to **Group 2.**

For Group 2 the experiment proceeds as follows:

- *Part I.* We present different tasks to you. We ask you to assess these tasks in different dimensions.
- *Part II.* You divide money between members of Group 1 for different scenarios.
- *Part III.* We ask you to fill in a general questionnaire.

  Please read the instructions carefully and give your honest opinion.

Next

1 Matching

In the next step one pair of participants from Group 1 will be randomly assigned to you.

Pair 001 from Group 1 has been assigned to you.

In the second part of the experiment we will introduce you to various scenarios where the members of Pair 001 have to complete calculation- and ball-tasks, respectively. For each of these scenarios we will ask you to divide money between the members of Pair 001. At the end of the experiment one scenario and one of your answers will be chosen randomly and implemented. In case Pair 001 has been assigned to another member of Group 2 as well, it will be decided randomly whose answer will be implemented. The total payment that a member of Pair 001 receives consists of a $10 fixed payment plus the amount of money you allocate to him/her.

Note that Pair 001 consists of two real people who will really do the tasks stated in the scenario that is randomly selected. And note that you will decide about the actual distribution of money between these two people.

Given that your decisions affect people, you should pay proper attention to them!

In the following you find a schematic structure of the assignment.

A member of Pair 001...	**You...**
...completes assigned tasks, ...gets a fixed payment of $10 + a payment depending on your decisions	...choose divisions of money for Pair 001, ...get a fixed payment of $5

The amount of money you can divide between these two people depends on the number of tasks each person completes. **Note that the people are not able to choose the type or the number of tasks they have to complete.** They can only decide to drop out of the experiment completely, in which case they do not receive any payment. After completing his/her assigned number of tasks, a member of Pair 001 can leave immediately and receives his/her payment automatically via transfer.

Can members of Pair 001 choose the type (i.e. calculation- or ball-tasks) or the number of tasks they have to complete? Enter...

... 1, if you think that they can choose the type and the number.

... 2, if you think that they can choose the type but not the number.

... 3, if you think that they can choose the number but not the type.

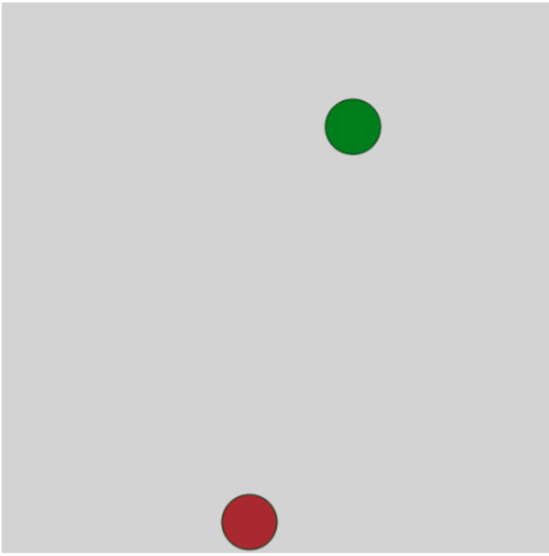
... 4, if you think that they can choose neither the type nor the number.

Next

Assessment of tasks: Ball-Task

Please solve the following ball-task. This means clicking on the "Left-" and "Right-"buttons to move the red ball to catch 10 green balls. If you miss a ball this counts as -1 ball caught.

Counter: 0



Left Right

Assessment of tasks: Calculation-Task

Please solve the following calculation-task. We kindly ask you to complete this task without a calculator, so that we can get your unbiased assessment of this task.

3 x 3 - 2 =	
5 x 4 + 6 =	
7 x 7 - 9 =	
1 x 7 - 3 =	
5 x 4 - 2 =	
2 x 6 - 2 =	
7 x 3 - 3 =	
5 x 2 - 4 =	
1 x 1 + 3 =	
2 x 3 + 7 =	

Next

1 Assessment of tasks

You just have experienced how 1 **ball-task** (i.e. catching ten balls) and 1 **calculation-task** (i.e. solving ten calculation problems) is like. Now we ask you to compare these tasks to each other.

calculation-tasks vs. ball-tasks:

100 calculation-tasks are [--------- ▾] 100 ball-tasks.

The more tedious task is [ ] percent more **tedious** than the other task. (*Example: If you think that one task is 10% more tedious than the other task, enter 10. If you think that one task is 100% more tedious (i.e. twice as tedious) than the other task, then enter 100. If you think that both tasks are equally tedious, enter 0.*)

100 calculation-tasks are [--------- ▾] 100 ball-tasks.

The more intellectually demanding task is [ ] percent more **intellectually demanding** than the other task.

100 calculation-tasks are [--------- ▾] 100 ball-tasks.

The more toilsome task is [ ] percent more **toilsome** than the other task.

time requirement

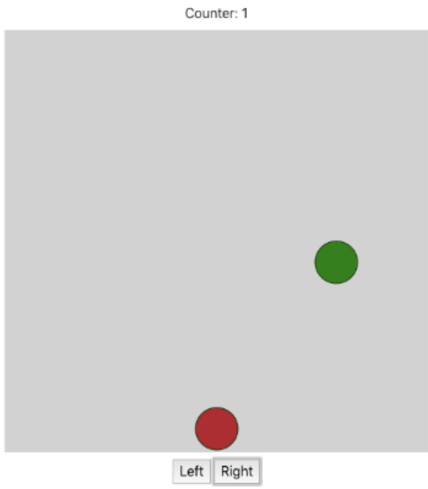
I expect that the average participant of this experiment will need [ ] minutes to complete 100 ball-tasks.

I expect that the average participant of this experiment will need [ ] minutes to complete 100 calculation-tasks.

Next

2.1 Scenario 1

For the first scenario one member of Pair 001 completes calculation-tasks (henceforth called "Calculator") and the other member completes ball-tasks (henceforth called "Ball-Catcher"). Here is a reminder how one calculation-task and one ball-task look like.



Subsequently we will present you tables that represent different relations between the number of completed tasks and the amount of money you can divide. One example of such a table is shown below.

- In the first column you see the number of calculation-tasks that the Calculator has to complete.
- In the first row you see the number of ball-tasks that the Ball-Catcher has to complete.
- The corresponding cell in the table contains the amount of money you can divide.

For instance, if the Calculator completes 100 calculation-tasks and the Ball-Catcher completes 200 ball-tasks, there are $30 that you can divide between Calculator and Ball-Catcher.

variant (i)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$20 to divide	$30 to divide
Calculator completes 300 calculation-tasks	$30 to divide	$40 to divide

2.1 Scenario 1

We start with variant(i). Please indicate which division of money you consider to be **fair.** You can choose the division by adjusting the slider in the table (the initial position of the slider is random).

variant (i)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$20 to divide: **Calculator should receive $** 18 **and Ball-Catcher should receive the remainder**	$30 to divide
Calculator completes 200 calculation-tasks	$30 to divide	$40 to divide

Next

2.1 Scenario 1

We start with variant(i). Please indicate which division of money you consider to be **fair.** You can choose the division by adjusting the slider in the table (the initial position of the slider is random).

variant (i)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$20 to divide	$30 to divide
Calculator completes 200 calculation-tasks	$30 to divide	$40 to divide

Consider the case highlighted in grey: If the Calculator receives $18, the Ball-Catcher receives $

Next

2.1 Scenario 1

We now proceed with variant(ii). Please indicate which division of money you consider to be **fair.**

variant (ii)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$30 to divide	$50 to divide: **Calculator should receive $** 22 **and Ball-Catcher should receive the remainder**
Calculator completes 200 calculation-tasks	$40 to divide	$60 to divide

Next

2.1 Scenario 1

We now proceed with variant(ii). Please indicate which division of money you consider to be **fair.**

variant (ii)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	\$30 to divide	\$50 to divide
Calculator completes 200 calculation-tasks	\$40 to divide	\$60 to divide

Suppose the Calculator completes 100 tasks and the Ball-Catcher completes 100 tasks as well, so that you can divide \$30. If the Ball-Catcher completes 200 tasks instead (while the Calculator still completes 100 tasks), you can divide \$50. By how much does the amount of money that you can divide increases, if the number of tasks for the Ball-Catcher increases from 100 to 200 (while Calculator still completes 100 tasks)?

Next

2.1 Scenario 1

You can revise now your fair divisions of money, if you like. When you completed all revisions or when you do not want to revise anything, click on the "Next"-button.

variant (i)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Your choice: $18 for Calculator and $2 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $20 and Ball-Catcher should receive the remainder.	Your choice: $19 for Calculator and $11 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $30 and Ball-Catcher should receive the remainder.
Calculator completes 200 calculation-tasks	Your choice: $1 for Calculator and $29 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $30 and Ball-Catcher should receive the remainder.	Your choice: $23 for Calculator and $17 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $40 and Ball-Catcher should receive the remainder.

variant (ii)	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Your choice: $23 for Calculator and $7 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $30 and Ball-Catcher should receive the remainder.	Your choice: $22 for Calculator and $28 for Ball-Catcher Revision: Calculator should receive $ [ ] of the $50 and Ball-Catcher should receive the remainder.
	Your choice: $38 for Calculator and $2 for Ball-	Your choice: $46 for Calculator and $14 for Ball-

2.2 Scenario 2 (60% completed)

In the previous scenario, members of Pair 001 received a fixed payment of $10 plus an amount of money you decided upon. In this scenario, members of Pair 001 receive **no fixed payment, but only the amount of money you decide upon** in the following. Please indicate which division of money you consider to be **fair.**

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$40 to divide: **Calculator should receive $** 10 **and Ball-Catcher should receive the remainder**	$50 to divide
Calculator completes 200 calculation-tasks	$50 to divide	$60 to divide

Next

2.2 Scenario 2 (60% completed)

In the previous scenario, members of Pair 001 received a fixed payment of $10 plus an amount of money you decided upon. In this scenario, members of Pair 001 receive **no fixed payment, but only the amount of money you decide upon** in the following. Please indicate which division of money you consider to be **fair.**

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	$40 to divide	$50 to divide
Calculator completes 200 calculation-tasks	$50 to divide	$60 to divide

Calculator and Ball-Catcher perform the tasks as the two members of Pair 001. How many members does Pair 001 have?

Next

2.2 Scenario 2 (60% completed)

You can revise now your fair divisions of money, if you like. When you completed all revisions or when you do not want to revise anything, click on the "Next"-button.

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-task	Your choice: $10 for Calculator and $30 for Ball-Catcher Revision: Calculator should receive $ of the $40 and Ball-Catcher should receive the remainder.	Your choice: $16 for Calculator and $34 for Ball-Catcher Revision: Calculator should receive $ of the $50 and Ball-Catcher should receive the remainder.
Calculator completes 200 calculation-tasks	Your choice: $1 for Calculator and $49 for Ball-Catcher Revision: Calculator should receive $ of the $50 and Ball-Catcher should receive the remainder.	Your choice: $1 for Calculator and $59 for Ball-Catcher Revision: Calculator should receive $ of the $60 and Ball-Catcher should receive the remainder.

Next

2.3 Scenario 3 (70% completed)

In the scenarios so far, the members of Pair 001 could neither choose the number of tasks (100 vs. 200) nor the type of tasks (ball vs. calculation) they had to complete. In this scenario

- the Calculator can choose whether he/she wants to complete 100 or 200 calculation-tasks and
- the Ball-Catcher can choose whether he/she wants to complete 100 or 200 ball-tasks.

Note that the members of Pair 001 still cannot choose the type of task they complete, i.e. whether they are the Calculator or the Ball-Catcher. They decide about the number of tasks given the division of money you considered to be fair in scenario 1. A member of Pair 001 is informed only about his/her individual payment depending on his/her own number of completed tasks.

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Calculator should receive \$ 18 , Ball-Catcher should receive \$ 2	Calculator should receive \$ 19 , Ball-Catcher should receive \$ 11
Calculator completes 200 calculation-tasks	Calculator should receive \$ 1 , Ball-Catcher should receive \$ 29	Calculator should receive \$ 23 , Ball-Catcher should receive \$ 17

Consider the following situation: Given the fair division of money you set before (see table above), Calculator chooses to complete 100 calculation-tasks and Ball-Catcher chooses to complete 100 ball-tasks (this corresponds to the grey cell in the table above). You can now divide \$30 between them, but you have to give Calculator at least \$18 and Ball-Catcher at least \$2. Please indicate which division of money you consider to be **fair:**

Calculator should receive \$ ______ of the **\$30** and Ball-Catcher the remainder.

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Calculator should receive \$ 18 , Ball-Catcher should receive \$ 2	Calculator should receive \$ 19 , Ball-Catcher should receive \$ 11
Calculator completes 200 calculation-tasks	Calculator should receive \$ 1 , Ball-Catcher should receive \$ 29	Calculator should receive \$ 23 , Ball-Catcher should receive \$ 17

Consider now the following situation: Given the fair division of money you set before (see table above), Calculator chooses to complete 100 calculation-tasks and Ball-Catcher chooses to complete 200 ball-tasks (this corresponds to the grey cell in the table above). You can now divide \$40 between them, but you have to give Calculator at least \$19 and Ball-Catcher at least \$11 . Please indicate which division of money you consider to be **fair:**

Calculator should receive \$ ______ of the **\$40** and Ball-Catcher the remainder.

2.3 Scenario 3 (70% completed)

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Calculator should receive $ 18 , Ball-Catcher should receive $ 2	Calculator should receive $ 19 , Ball-Catcher should receive $ 11
Calculator completes 200 calculation-tasks	Calculator should receive $ 1 , Ball-Catcher should receive $ 29	Calculator should receive $ 23 , Ball-Catcher should receive $ 17

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-tasks	Calculator should receive $ 18 , Ball-Catcher should receive $ 2	Calculator should receive $ 19 , Ball-Catcher should receive $ 11
Calculator completes 200 calculation-tasks	Calculator should receive $ 1 , Ball-Catcher should receive $ 29	Calculator should receive $ 23 , Ball-Catcher should receive $ 17

Consider the following situation: The Calculator completes 100 calculation-tasks and the Ball-Catcher completes 200 ball-tasks. If you read the survey until this sentence, ignore this text and just write the number fifty in the following form.

50

Next

2.4 Scenario 4 (80% completed)

Consider that both, the Calculator and the Ball-Catcher, state that they experience **100 calculation-tasks 100% more toilsome than 100 ball-tasks** (i.e. twice as toilsome). Please indicate which division of money you consider to be **fair.**

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-task	$20 to divide	$30 to divide
Calculator completes 200 calculation-tasks	$30 to divide: **Calculator should receive $** 14 **and Ball-Catcher should receive the remainder**	$40 to divide

Next

2.4 Scenario 4 (80% completed)

You can revise now your fair divisions of money, if you like. When you completed all revisions or when you do not want to revise anything, click on the "Next"-button.

	Ball-Catcher completes 100 ball-tasks	Ball-Catcher completes 200 ball-tasks
Calculator completes 100 calculation-task	Your choice: $12 for Calculator and $8 for Ball-Catcher Revision: Calculator should receive $ ___ of the $20 and Ball-Catcher should receive the remainder.	Your choice: $29 for Calculator and $1 for Ball-Catcher Revision: Calculator should receive $ ___ of the $30 and Ball-Catcher should receive the remainder.
Calculator completes 200 calculation-tasks	Your choice: $14 for Calculator and $16 for Ball-Catcher Revision: Calculator should receive $ ___ of the $30 and Ball-Catcher should receive the remainder.	Your choice: $8 for Calculator and $32 for Ball-Catcher Revision: Calculator should receive $ ___ of the $40 and Ball-Catcher should receive the remainder.

Next

2.5 Scenario 5 (90% completed)

In the previous scenarios, the member of Pair 001 complete different tasks. In this scenario, **both members of Pair 001 complete calculation-tasks!** They are thus called "Calculator 1" and "Calculator 2". Here is a reminder how the calculation-task looks like.

3 x 3 - 2 =	
5 x 4 + 6 =	
7 x 7 - 9 =	
1 x 7 - 3 =	
5 x 4 - 2 =	
2 x 6 - 2 =	
7 x 3 - 3 =	
5 x 2 - 4 =	
1 x 1 + 3 =	
2 x 3 + 7 =	

Next

Next

2.5 Scenario 5 (90% completed)

In this scenario, **both members of Pair 001 complete calculation-tasks!** They are thus called "Calculator 1" and "Calculator 2" here.
Please indicate which division of money you consider to be **fair.**

	Calculator 2 completes 100 calculation-tasks	Calculator 2 completes 200 calculation-tasks
Calculator 1 completes 100 calculation-tasks	$20 to divide: **Calculator 1 should receive $** 10 **and Calculator 2 should receive the remainder**	$30 to divide
Calculator 1 completes 200 calculation-tasks	$30 to divide	$40 to divide

Next

3 Questionnaire (95% completed)

Part II is now completed. In the final Part III we ask you to answer a brief questionnaire.

- What is your country of birth?
- Year of birth?
- What is your gender?

- What is your highest educational attainment? If your degree is not present in the following drop-down menu, please select the option that comes closest to your highest educational attainment.

- What is your current main occupation? If you spend most of your time at an educational institution, please indicate the field of your apprenticeship, study, etc.
- What was your total *net labor income* last year?

- In how many economic or psychological experiments or surveys did you participate before this one?

Next

3 Questionnaire (95% completed)

Please describe – if possible – what principles or rules you followed while dividing the money between the members in your pair.

Next

3 Questionnaire (95% completed)

Please answer the following questions concerning your views on different economic policies.
Please rate from 1 (do not agree at all) to 5 (fully agree). Leave the button blank, if you are not able to answer the question.

Substantial labor taxes on high labor incomes generally lead to more fairness.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

The adoption of maximum wages generally leads to more fairness.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Wage subsidies on low wages generally leads to more fairness.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

The adoption of minimum wages generally leads to more fairness.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Next

3 Questionnaire (95% completed)

Please answer the following questions concerning the determinants of wages.
Please rate from 1 (do not agree at all) to 5 (fully agree). Leave the button blank, if you are not able to answer the question.

From a fairness perspective, the monthly **labor income** of an employee should reflect...

...the value of the work for the employer.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...how toilsome the work is.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...how intellectually demanding the work is.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...what the employer offers.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...the talent that is necessary for the work.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...the number of working hours.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

....how tedious the work is.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...the value of the work for society.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

...the level/amount of education and qualification that is necessary for the work.
○ 1 ○ 2 ○ 3 ○ 4 ○ 5

Next

3 Concluding Remarks (100% completed)

This is the end of the experiment. We are very grateful for your participation.

Due to the nature of our experiment, we could not disclose its intent when you accepted our consent form. However, below is full disclosure of the intent of our experiment. If you have any questions or concerns, feel free to contact the principal investigators:

1. Marius Vogel, University of Cologne (Germany), marius.vogel@wiso.uni-koeln.de

2. Dr. Dr. Raphael Flore, University of Cologne (Germany), flore@wiso.uni-koeln.de

An important question in economics is how the joint output of a society should be distributed among its members. According to economic theory, in a free market economy a person earns what he or she adds to economic output. We want to study whether this is regarded as **fair** or whether other aspects – like quantity or the type of input someone provides – are important from a fairness perspective. For this purpose we asked you to divide money for varying quantities, productivities and types of inputs these two people provided.

Thank you very much for your participation in this experiment! Your payment will be automatically transferred to your MTurk account in three days.

If you like, you can give us some brief feedback on the experiment. We would greatly appreciate to hear your opinion!

- Have you had the feeling that the questions of the survey were biased? Did they push you towards a specific viewpoint?

- If so, can you describe why the questions were biased?
- Did you find any part of this survey confusing?

- If so, can you explain why?
- Do you have any other thoughts about the survey that you would like to share?

4.E Appendix: Stata Code

```
log close _all
clear all
set more off
set graphics off

cd "/home/mv/Dropbox/Raphael-Marius-Ordner/Data" /* path Marius
    */
log using fairprices_cleaning_log.log, replace

import delimited "All apps - wide (accessed 2019-03-11).csv"
gen fixedpaymessedup = 1
label var fixedpaymessedup `"for consequentialism these obs have
    to be dropped"'
save alldata.dta, replace
clear

import delimited "All apps - wide (accessed 2019-03-12).csv"
append using alldata.dta, force
save alldata.dta, replace
clear

import delimited "All apps - wide (accessed 2019-03-25).csv"
append using alldata.dta, force
save alldata.dta, replace
clear

import delimited "All apps - wide (accessed 2019-03-31).csv"
append using alldata.dta, force
save alldata.dta, replace
clear

use alldata.dta

***basic data cleaning***

keep if participant_index_in_pages == 101

```

```
sort participantmturk_worker_id

drop participantid_in_session participantcode participantlabel participant_is_bot participant_index_in_pages participant_max_page_index participant_current_app_name participant_round_number participant_current_page_name participantip_address participantvisited participantmturk_assignment_id participantpayoff participantpayoff_plus_participa sessionlabel sessionexperimenter_name sessionmturk_hitid sessionmturk_hitgroupid sessioncomment sessionis_demo sessionconfigparticipation_fee sessionconfigreal_world_currency intro1playerid_in_group intro1playermturkid intro1playerrand_payment intro1playersubsession_id intro1playergroup_id intro1playerpayoff intro1groupid_in_subsession intro1groupsubsession_id intro1subsessionround_number tasks_intro1playerid_in_group

label variable participanttime_started `"Start time of the experiment"'
label variable participantmturk_worker_id `"MTurk ID"'
label variable sessioncode `"Code of Session"'

label variable tasks_intro1playerassquest1 `"100 calculation-tasks are [1=more/2=equallly/3=less] tedious than 100 ball-tasks"'
label variable tasks_intro1playerassquest2 `"The more tedious task is x percent more tedious than the other task"'
label variable tasks_intro1playerassquest3 `"100 calculation-tasks are [1=more/2=equallly/3=less] intelectually demanding than 100 ball-tasks"'
label variable tasks_intro1playerassquest4 `"The more int. dem. task is x percent more inte dem than the other task"'
label variable tasks_intro1playerassquest5 `"100 calculation-tasks are [1=more/2=equallly/3=less] toilsome than 100 ball-tasks"'
label variable tasks_intro1playerassquest6 `"The more toilsome task is x percent more toilsome than the other task"'
```

```
label variable tasks_intro1playerassquest7 `"I expect ... need x
    minutes to complete 100 ball-tasks."'
label variable tasks_intro1playerassquest8 `"I expect ... need x
    minutes to complete 100 calculation-tasks."'

drop tasks_intro1playersubsession_id tasks_intro1playergroup_id
   tasks_intro1playerpayoff tasks_intro1groupid_in_subsessio
   tasks_intro1groupsubsession_id
   tasks_intro1subsessionround_numb
   scenario_start1playerid_in_group

label variable scenario_start1playercontrollque `"Control (
   correct=4) Can members choose type or number of tasks they
   have to complete?"'
rename scenario_start1playercontrollque controlquestion_1_choose

drop *subsession* *group* *payoff* *playerid* *playersub* *
   playerpay*

rename scenario_start1playerscenario11
   scenario111playerscenario11

label variable scenario_start_after1playercontr `"Control (
   correct=17) Consider the case highlighted in grey: If the
   Calculator receives $3, the Ball-Catcher receives"'
rename scenario_start_after1playercontr
   controlquestion_2_remainder

gen scenario1a_100b100c = scenario111playerscenario11
label variable scenario1a_100b100c `"Scenario 1a (baseline): 100
    balls and 100 calculation"'
drop scenario111playerscenario11

egen scenario1a_200b100c = rowtotal(scenario111playerscenario12
   scenario112playerscenario12 scenario113playerscenario12)
label variable scenario1a_200b100c `"Scenario 1a (baseline): 200
    balls and 100 calculation"'
drop scenario111playerscenario12 scenario112playerscenario12
   scenario113playerscenario12
```

```
egen scenario1a_100b200c = rowtotal(scenario111playerscenario13
    scenario112playerscenario13 scenario113playerscenario13)
label variable scenario1a_100b200c `"Scenario 1a (baseline): 100
     balls and 200 calculation"'
drop scenario111playerscenario13 scenario112playerscenario13
    scenario113playerscenario13

egen scenario1a_200b200c = rowtotal(scenario111playerscenario14
    scenario112playerscenario14 scenario113playerscenario14)
label variable scenario1a_200b200c `"Scenario 1a (baseline): 200
     balls and 200 calculation"'
drop scenario111playerscenario14 scenario112playerscenario14
    scenario113playerscenario14

egen scenario1b_100b100c = rowtotal(scenario121playerscenario15
    scenario122playerscenario15 scenario123playerscenario15
    scenario124playerscenario15)
label variable scenario1b_100b100c `"Scenario 1b (productivity):
     100 balls and 100 calculation"'
drop scenario121playerscenario15 scenario122playerscenario15
    scenario123playerscenario15 scenario124playerscenario15

egen scenario1b_200b100c = rowtotal(scenario121playerscenario16
    scenario122playerscenario16 scenario123playerscenario16
    scenario124playerscenario16)
label variable scenario1b_200b100c `"Scenario 1b (productivity):
     200 balls and 100 calculation"'
drop scenario121playerscenario16 scenario122playerscenario16
    scenario123playerscenario16 scenario124playerscenario16

egen scenario1b_100b200c = rowtotal(scenario121playerscenario17
    scenario122playerscenario17 scenario123playerscenario17
    scenario124playerscenario17)
label variable scenario1b_100b200c `"Scenario 1b (productivity):
     100 balls and 200 calculation"'
drop scenario121playerscenario17 scenario122playerscenario17
    scenario123playerscenario17 scenario124playerscenario17

```

```
egen scenario1b_200b200c = rowtotal(scenario121playerscenario18 scenario122playerscenario18 scenario123playerscenario18 scenario124playerscenario18)
label variable scenario1b_200b200c `"Scenario 1b (productivity): 200 balls and 200 calculation"'
drop scenario121playerscenario18 scenario122playerscenario18 scenario123playerscenario18 scenario124playerscenario18

label variable scenario12_controll1playercontro `"Control (correct=20) By how much does the amount of money that you can divide increases?"'
rename scenario12_controll1playercontro controlquestion_3_mps

rename scenario131playerchangescenario1 scenario1a_100b100c_rev
label variable scenario1a_100b100c_rev `"Scenario 1a revision (baseline): 100 balls and 100 calculation"'
replace scenario1a_100b100c_rev = scenario1a_100b100c if scenario1a_100b100c_rev==.

rename v158 scenario1a_200b100c_rev
label variable scenario1a_200b100c_rev `"Scenario 1a revision (baseline): 200 balls and 100 calculation"'
replace scenario1a_200b100c_rev = scenario1a_200b100c if scenario1a_200b100c_rev==.

rename v159 scenario1a_100b200c_rev
label variable scenario1a_100b200c_rev `"Scenario 1a revision (baseline): 100 balls and 200 calculation"'
replace scenario1a_100b200c_rev = scenario1a_100b200c if scenario1a_100b200c_rev==.

rename v160 scenario1a_200b200c_rev
label variable scenario1a_200b200c_rev `"Scenario 1a revision (baseline): 200 balls and 200 calculation"'
replace scenario1a_200b200c_rev = scenario1a_200b200c if scenario1a_200b200c_rev==.

rename v161 scenario1b_100b100c_rev
```

```
label variable scenario1b_100b100c_rev `"Scenario 1b revision (productivity): 100 balls and 100 calculation"'
replace scenario1b_100b100c_rev = scenario1b_100b100c if scenario1b_100b100c_rev==.

rename v162 scenario1b_200b100c_rev
label variable scenario1b_200b100c_rev `"Scenario 1b revision (productivity): 200 balls and 100 calculation"'
replace scenario1b_200b100c_rev = scenario1b_200b100c if scenario1b_200b100c_rev==.

rename v163 scenario1b_100b200c_rev
label variable scenario1b_100b200c_rev `"Scenario 1b revision (productivity): 100 balls and 200 calculation"'
replace scenario1b_100b200c_rev = scenario1b_100b200c if scenario1b_100b200c_rev==.

rename v164 scenario1b_200b200c_rev
label variable scenario1b_200b200c_rev `"Scenario 1b revision (productivity): 200 balls and 200 calculation"'
replace scenario1b_200b200c_rev = scenario1b_200b200c if scenario1b_200b200c_rev==.

egen scenario2_100b100c = rowtotal(scenario211playerscenario21 scenario212playerscenario21 scenario213playerscenario21 scenario214playerscenario21)
label variable scenario2_100b100c `"Scenario 2 (fixed pay): 100 balls and 100 calculation"'
drop scenario211playerscenario21 scenario212playerscenario21 scenario213playerscenario21 scenario214playerscenario21

egen scenario2_200b100c = rowtotal(scenario211playerscenario22 scenario212playerscenario22 scenario213playerscenario22 scenario214playerscenario22)
label variable scenario2_200b100c `"Scenario 2 (fixed pay): 200 balls and 100 calculation"'
drop scenario211playerscenario22 scenario212playerscenario22 scenario213playerscenario22 scenario214playerscenario22

```

```
egen scenario2_100b200c = rowtotal(scenario211playerscenario23 scenario212playerscenario23 scenario213playerscenario23 scenario214playerscenario23)
label variable scenario2_100b200c `"Scenario 2 (fixed pay): 100 balls and 200 calculation"'
drop scenario211playerscenario23 scenario212playerscenario23 scenario213playerscenario23 scenario214playerscenario23

egen scenario2_200b200c = rowtotal(scenario211playerscenario24 scenario212playerscenario24 scenario213playerscenario24 scenario214playerscenario24)
label variable scenario2_200b200c `"Scenario 2 (fixed pay): 200 balls and 200 calculation"'
drop scenario211playerscenario24 scenario212playerscenario24 scenario213playerscenario24 scenario214playerscenario24

label variable scenario221playercontrollquest4 `"Control (correct=2) How many members does Pair 003 have?"'
rename scenario221playercontrollquest4 controlquestion_4_pair

rename scenario231playerchangescenario2 scenario2_100b100c_rev
label variable scenario2_100b100c_rev `"Scenario 2 revision (fixed pay): 100 balls and 100 calculation"'
replace scenario2_100b100c_rev = scenario2_100b100c if scenario2_100b100c_rev==.

rename v225 scenario2_200b100c_rev
label variable scenario2_200b100c_rev `"Scenario 2 revision (fixed pay): 200 balls and 100 calculation"'
replace scenario2_200b100c_rev = scenario2_200b100c if scenario2_200b100c_rev==.

rename v226 scenario2_100b200c_rev
label variable scenario2_100b200c_rev `"Scenario 2 revision (fixed pay): 100 balls and 200 calculation"'
replace scenario2_100b200c_rev = scenario2_100b200c if scenario2_100b200c_rev==.

rename v227 scenario2_200b200c_rev
```

```
label variable scenario2_200b200c_rev `"Scenario 2 revision (
    fixed pay): 200 balls and 200 calculation"'
replace scenario2_200b200c_rev = scenario2_200b200c if
    scenario2_200b200c_rev==.

rename scenario321playerscenario31 scenario3_100b100c
label variable scenario3_100b100c `"Scenario 3 (quantity choice)
    : 100 balls and 100 calculation"'

rename scenario321playerscenario32 scenario3_200b100c
label variable scenario3_200b100c `"Scenario 3 (quantity choice)
    : 200 balls and 100 calculation"'

label variable scenario32_controll1playercontro `"Control (
    correct=50) If you read ... write the number fifty in the
    following form."'
rename scenario32_controll1playercontro controlquestion_5_awake

egen scenario4_100b100c = rowtotal(scenario411playerscenario41
    scenario412playerscenario41 scenario413playerscenario41
    scenario414playerscenario41)
label variable scenario4_100b100c `"Scenario 4 (stated toil):
    100 balls and 100 calculation"'
drop scenario411playerscenario41 scenario412playerscenario41
    scenario413playerscenario41 scenario414playerscenario41

egen scenario4_200b100c = rowtotal(scenario411playerscenario42
    scenario412playerscenario42 scenario413playerscenario42
    scenario414playerscenario42)
label variable scenario4_200b100c `"Scenario 4 (stated toil):
    200 balls and 100 calculation"'
drop scenario411playerscenario42 scenario412playerscenario42
    scenario413playerscenario42 scenario414playerscenario42

egen scenario4_100b200c = rowtotal(scenario411playerscenario43
    scenario412playerscenario43 scenario413playerscenario43
    scenario414playerscenario43)
label variable scenario4_100b200c `"Scenario 4 (stated toil):
    100 balls and 200 calculation"'
```

```
drop scenario411playerscenario43 scenario412playerscenario43
    scenario413playerscenario43 scenario414playerscenario43

egen scenario4_200b200c = rowtotal(scenario411playerscenario44
    scenario412playerscenario44 scenario413playerscenario44
    scenario414playerscenario44)
label variable scenario4_200b200c `"Scenario 4 (stated toil):
    200 balls and 200 calculation"'
drop scenario411playerscenario44 scenario412playerscenario44
    scenario413playerscenario44 scenario414playerscenario44

rename scenario421playerchangescenario4 scenario4_100b100c_rev
label variable scenario4_100b100c_rev `"Scenario 4 revision (
    stated toil): 100 balls and 100 calculation"'
replace scenario4_100b100c_rev = scenario4_100b100c if
    scenario4_100b100c_rev==.

rename v297 scenario4_200b100c_rev
label variable scenario4_200b100c_rev `"Scenario 4 revision (
    stated toil): 200 balls and 100 calculation"'
replace scenario4_200b100c_rev = scenario4_200b100c if
    scenario4_200b100c_rev==.

rename v298 scenario4_100b200c_rev
label variable scenario4_100b200c_rev `"Scenario 4 revision (
    stated toil): 100 balls and 200 calculation"'
replace scenario4_100b200c_rev = scenario4_100b200c if
    scenario4_100b200c_rev==.

rename v299 scenario4_200b200c_rev
label variable scenario4_200b200c_rev `"Scenario 4 revision (
    stated toil): 200 balls and 200 calculation"'
replace scenario4_200b200c_rev = scenario4_200b200c if
    scenario4_200b200c_rev==.

egen scenario5_100c100c = rowtotal(scenario521playerscenario51
    scenario522playerscenario51 scenario523playerscenario51
    scenario524playerscenario51)
```

```
label variable scenario5_100c100c `"Scenario 5 (calculation):
    100 calculation and 100 calculation"'
drop scenario521playerscenario51 scenario522playerscenario51
    scenario523playerscenario51 scenario524playerscenario51

egen scenario5_100c200c = rowtotal(scenario521playerscenario52
    scenario522playerscenario52 scenario523playerscenario52
    scenario524playerscenario52)
label variable scenario5_100c200c `"Scenario 5 (calculation):
    100 calculation and 200 calculation"'
drop scenario521playerscenario52 scenario522playerscenario52
    scenario523playerscenario52 scenario524playerscenario52

egen scenario5_200c100c = rowtotal(scenario521playerscenario53
    scenario522playerscenario53 scenario523playerscenario53
    scenario524playerscenario53)
label variable scenario5_200c100c `"Scenario 5 (calculation):
    200 calculation and 100 calculation"'
drop scenario521playerscenario53 scenario522playerscenario53
    scenario523playerscenario53 scenario524playerscenario53

egen scenario5_200c200c = rowtotal(scenario521playerscenario54
    scenario522playerscenario54 scenario523playerscenario54
    scenario524playerscenario54)
label variable scenario5_200c200c `"Scenario 5 (calculation):
    200 calculation and 200 calculation"'
drop scenario521playerscenario54 scenario522playerscenario54
    scenario523playerscenario54 scenario524playerscenario54

label variable questionnaire1playerage `"Year of birth?"'
replace questionnaire1playerage = . if questionnaire1playerage <
     1900 /* exclude typos */

label variable questionnaire1playernationality `"What is your
    country of birth?"'
replace questionnaire1playernationality = "USA" if
    questionnaire1playernationality != "Germany" &
    questionnaire1playernationality != "Canada" &
    questionnaire1playernationality != "Turkey"
```

```
replace questionnaire1playernationality = "DEU" if
    questionnaire1playernationality == "Germany"
replace questionnaire1playernationality = "CAN" if
    questionnaire1playernationality == "Canada"
replace questionnaire1playernationality = "TUR" if
    questionnaire1playernationality == "Turkey"

label variable questionnaire1playergender ‘"What is your gender
    ?"’
label define genderlabels 1 "m" 2 "f" 3 "o"
label values questionnaire1playergender genderlabels

label variable questionnaire1playerdegree ‘"What is your
    education?"’
label define degreelabels 1 "none" 2 "hs" 3 "ba" 4 "ma" 5 "PhD"
label values questionnaire1playerdegree degreelabels

label variable questionnaire1playeroccupation ‘"What is your
    current main occupation?"’

label variable questionnaire1playerlabor_income ‘"What was your
    total net labor income last year?"’/* [in smaller than
    multiples of USD 1000]*/
label define incomelabels 1 "0" 2 "10" 3 "15" 4 "20" 5 "25" 6
    "30" 7 "35" 8 "40" 9 "45" 10 "50" 11 "50+"
label values questionnaire1playerlabor_income incomelabels

label variable questionnaire1playeramount_surve ‘"In how many
    experiments did you participate?"’
label define explabels 1 "0" 2 "1" 3 "2" 4 "3" 5 "4" 6 "5" 7 "6"
    8 "7" 9 "8" 10 "9" 11 "10" 12 ">10"
label values questionnaire1playeramount_surve explabels

label variable questionnaire1playerdivision_pri ‘"Please
    describe what principles or rules you followed while dividing
    the money"’
label variable questionnaire1playerfirst_policy ‘"Wage subsidies
    lead to fairness"’
```

```
label variable questionnaire1playersecond_polic `"Maximum wages lead to fairness"'
label variable questionnaire1playerthird_policy `"Minimum wages lead to fairness"'
label variable questionnaire1playerfourth_polic `"Labor taxes lead to fairness"'

label variable questionnaire1playerquestion1 `"Labor income - value for the employer"'
label variable questionnaire1playerquestion2 `"Labor income - tedious"'
label variable questionnaire1playerquestion3 `"Labor income - toilsome"'
label variable questionnaire1playerquestion4 `"Labor income - education/qualification"'
label variable questionnaire1playerquestion5 `"Labor income - what the employer offers"'
label variable questionnaire1playerquestion6 `"Labor income - number of working hours"'
label variable questionnaire1playerquestion7 `"Labor income - intellectually demanding"'
label variable questionnaire1playerquestion8 `"Labor income - value for society"'
label variable questionnaire1playerquestion9 `"Labor income - necessary talent "'

label variable questionnaire1playerremark1 `"Have you had the feeling [...] questions [...] biased?"' /* `"Have you had the feeling that the questions of the survey were biased?"' */
label define remark1labels 1 "yes" 2 "no"
label values questionnaire1playerremark1 remark1labels

label variable questionnaire1playerremark2 `"If so, can you describe why the questions were biased?"'
label variable questionnaire1playerremark3 `"Did you find any part of this survey confusing?"'
label define remark3labels 1 "yes" 2 "no"
label values questionnaire1playerremark3 remark3labels
```

```
label variable questionnaire1playerremark4 `"If so, can you explain why?"'
label variable questionnaire1playerremark5 `"Do you have any other thoughts about the survey that you would like to share?"'

gen controlquestion_all = 1 if controlquestion_1_choose == 4 & controlquestion_2_remainder + scenario1a_100b100c == 20 & controlquestion_3_mps == 20 & controlquestion_4_pair == 2 & controlquestion_5_awake == 50
replace controlquestion_all = 0 if controlquestion_all != 1
label variable controlquestion_all `"Answered all control questions correctly?"'
label define controllabels 0 "no" 1 "yes"
label values controlquestion_all controllabels

drop questionnaire1playerdivision_pri questionnaire1playerremark2 questionnaire1playerremark4 questionnaire1playerremark5 /* to be able to use the savelold options*/

****computation of assessment of tasks in relative terms

gen tedious_rel = 1+tasks_intro1playerassquest2/100 if tasks_intro1playerassquest1==1
replace tedious_rel = 1/(1+tasks_intro1playerassquest2/100) if tasks_intro1playerassquest1!=1
label variable tedious_rel `"Tedious: calc relative to ball"'

gen ln_tedious = ln(tedious_rel)
label variable ln_tedious `"Log of tedious_rel"'

gen intdem_rel = 1+tasks_intro1playerassquest4/100 if tasks_intro1playerassquest3==1
replace intdem_rel = 1/(1+tasks_intro1playerassquest4/100) if tasks_intro1playerassquest3!=1
label variable intdem_rel `"Intellectually demanding: calc relative to ball"'

```

```
gen ln_intdem = ln(intdem_rel)
label variable ln_intdem `"Log of intdem_rel"'

gen toilsome_rel =  1+tasks_intro1playerassquest6/100 if tasks_intro1playerassquest5==1
replace toilsome_rel = 1/(1+tasks_intro1playerassquest6/100) if tasks_intro1playerassquest5!=1
label variable toilsome_rel `"Toilsome: calc relative to ball"'

gen ln_toilsome = ln(toilsome_rel)
label variable ln_toilsome `"Log of toilsome_rel"'

gen time_rel =  tasks_intro1playerassquest8/tasks_intro1playerassquest7
label variable time_rel `"Time: calc relative to ball"'

gen ln_time = ln(time_rel)
label variable ln_time `"Log of time_rel"'

factor ln_tedious ln_toilsome ln_time ln_intdem if controlquestion_all == 1
loadingplot, name(loadingplot1, replace) nodraw
rotate, orthogonal varimax
loadingplot, name(loadingplot2, replace) nodraw
graph combine loadingplot1 loadingplot2, name(loadingplot, replace) xsize(40) ysize(20) altshrink rows(1) ycommon xcommon
graph export graph_loadingplot.png, replace width(4000)

predict ln_factor1 ln_factor2 if controlquestion_all == 1

***Umstrukturierung des Datenssatzes, sodass jede Verteilung eines Teilnehmers als independent

reshape long scenario, i(participantmturk_worker_id) j(cell, string)
label variable cell `"Scenario (with number/type of tasks)"'
egen integercell=group(cell)
```

```
label variable integercell `"Scenario string replaced by integer to utilize Panel structure"'

label define cellvalue 2 "Scenario 1(i): 100 ball, 100 calc" 4 "Scenario 1(i): 100 ball, 200 calc" 6 "Scenario 1(i): 200 ball, 100 calc" 8 "Scenario 1(i): 200 ball, 200 calc" 10 "Scenario 1(ii): 100 ball, 100 calc" 12 "Scenario 1(ii): 100 ball, 200 calc" 14 "Scenario 1(ii): 200 ball, 100 calc" 16 "Scenario 1(ii): 200 ball, 200 calc" 35 "Scenario 5: 100 calc, 100 calc" 36 "Scenario 5: 100 calc, 200 calc" 37 "Scenario 5: 200 calc, 100 calc" 38 "Scenario 5: 200 calc, 200 calc"
label value integercell cellvalue

rename scenario compensation
label variable compensation `"Compensation which the Calculator receives"'

rename participantmturk_worker_id ID
replace ID = "A" if ID ==""
egen integerID=group(ID)
label variable integerID `"MTurk ID replaced by integer to utilize Panel structure"'

tsset integerID integercell

gen revision = strmatch(cell,"*_rev")
label variable revision `"revised statement? (1 if yes)"'

gen scenario_number = real(substr(cell,1,1))
label variable scenario_number `"number of scenario"'

gen fixedpay = 0 if scenario_number == 2
replace fixedpay = 10 if fixedpay !=0
label variable fixedpay `"fixed payment each worker receives initially"'

gen not2calc = 0 if scenario_number == 5
replace not2calc = 1 if scenario_number != 5
```

```
label variable not2calc `"Dummy that equals 1 for Calculation-Balls-scenarios"'

gen calctasks = 100 if 1==strmatch(cell,"*100c*")
replace calctasks = 200 if calctasks != 100
replace calctasks = 200 if 1==strmatch(cell,"*200c100c*")  /* special case in calc-calc-scenario */
label variable calctasks `"number of tasks completed by Calculator"'

gen secondtasks = 100 if 1==strmatch(cell,"*100b*")
replace secondtasks = 200 if secondtasks != 100
replace secondtasks = 100 if 1==strmatch(cell,"*100c100c*")  /* special case in calc-calc-scenario */
replace secondtasks = 100 if 1==strmatch(cell,"*200c100c*")  /* special case in calc-calc-scenario */
label variable secondtasks `"number of tasks completed by Person 2 (balls in Scen. 1-4, calc. in Scen. 5)"'

gen quantrel = calctasks/secondtasks
label variable quantrel `"number of Calculator-tasks relative to number of tasks of Person 2 (balls in Scen. 1-4, calc. in Scen. 5)"'

gen ln_quantrel = ln(quantrel)
label variable ln_quantrel `"lnquant"'

gen prodrel = 0.5 if 1==strmatch(cell,"1b*")
replace prodrel = 1 if 1!=strmatch(cell,"1b*")
label variable prodrel `"productivity of calc.-tasks relative to ball-tasks"'

gen ln_prodrel = ln(prodrel)
label variable ln_prodrel `"lnprod"'

gen ln_timeadj = ln_time
replace ln_timeadj = 0 if not2calc != 1
label variable ln_timeadj `"lntime"'
```

```
gen ln_tediousadj = ln_tedious
replace ln_tediousadj = 0 if not2calc != 1
label variable ln_tediousadj `"lntedious"'

gen ln_intdemadj = ln_intdem
replace ln_intdemadj = 0 if not2calc != 1
label variable ln_intdemadj `"lnintdem"'

gen ln_toilsomeadj = ln_toilsome
replace ln_toilsomeadj = 0 if not2calc != 1
label variable ln_toilsomeadj `"lntoilsome"'

gen ln_factor1adj = ln_factor1
replace ln_factor1adj = 0 if not2calc != 1
label variable ln_factor1adj `"lnfactor1"'

gen ln_factor2adj = ln_factor2
replace ln_factor2adj = 0 if not2calc != 1
label variable ln_factor2adj `"lnfactor2"'

gen output = 0.1*secondtasks/prodrel+0.1*calctasks
replace output = output + 20 if scenario_number ==2
replace output = output + 10 if scenario_number ==3
label variable output `"money that can be divided between the
    workers"'

gen compshare = compensation/output
label variable compshare `"share of distributable money that the
     Calculator receives"'

gen comptotal = compensation+fixedpay
label variable comptotal `"Compensation incl. fixed payment
    Calculator receives"'

gen comprel = compensation/(output-compensation)
label variable comprel `"size of Calculator compensation
    relative to compensation of Person 2 (balls in Scen. 1-4,
    calc. in Scen. 5)"'

```

```
replace comprel = 100 if compshare == 1 /* modify values to deal
    with ln */
replace comprel = 0.01 if compshare == 0 /* modify values to
    deal with ln */

gen ln_comprel = ln(comprel)
label variable ln_comprel `"lncomp"'

***generate qualitysubject

scalar p=1
gen ca = ln_comprel
label var ca `"auxiliary var that can be replaced for different
    stuff in loss function"'
gen loss_aux = abs(F1.ca)^p+abs(F3.ca)^p+abs(F5.ca)^p+abs(F7.ca)
    ^p+abs(F9.ca)^p+abs(F11.ca)^p+abs(F13.ca)^p+abs(F15.ca)^p+abs
    (F17.ca)^p+abs(F19.ca)^p+abs(F21.ca)^p+abs(F23.ca)^p+abs(F24.
    ca)^p+abs(F25.ca)^p+abs(F27.ca)^p+abs(F29.ca)^p+abs(F31.ca)^p
    +abs(F33.ca)^p+abs(F34.ca)^p+abs(F35.ca)^p+abs(F36.ca)^p+abs(
    F37.ca)^p
replace loss_aux = L1.loss_aux if missing(loss_aux)
label var loss_aux `"individual loss function"'
drop ca
scalar drop p

gen notstrictequalizer = 1 if abs(loss_aux) >0
replace notstrictequalizer = 0 if notstrictequalizer != 1
label var notstrictequalizer `"Deviated from 50/50 at least once
    ?"'
label define equalizerlabels 0 "no" 1 "yes"
label values notstrictequalizer equalizerlabels

gen qualitysubject = controlquestion_all*notstrictequalizer
label var qualitysubject `"All control questions correct and no
    strict eqaulizer?"'
label define qualitylabels 0 "no" 1 "yes"
label values qualitysubject qualitylabels

gen hetero = integerID*not2calc
```

```
label var hetero ‘"auxiliary var =0 for equal tasks and = integerID else"’

***Generate Fairness Ideals

gen ln_equality = -ln_quantrel
label var ln_equality ‘"auxiliary var such that loop below works"’
gen ln_equity = 0
label var ln_equity ‘"auxiliary var such that loop below works"’

foreach power in 1 2 3 4 {
foreach t in ln ratio share {
foreach y in equality equity prodrel tediousadj toilsomeadj timeadj intdemadj {

scalar p = ‘power’
gen ca_ln = ln_comprel - ln_quantrel - ln_‘y’
gen ca_ratio = exp(ln_comprel) - exp(ln_quantrel - ln_‘y’)
gen ca_share = exp(ln_comprel)/(1+exp(ln_comprel)) - exp(ln_quantrel - ln_‘y’)/(1+exp(ln_quantrel - ln_‘y’))
gen loss_‘y’ = (abs(F1.ca_‘t’)^p+abs(F3.ca_‘t’)^p+abs(F5.ca_‘t’)^p+abs(F7.ca_‘t’)^p+abs(F9.ca_‘t’)^p+abs(F11.ca_‘t’)^p+abs(F13.ca_‘t’)^p+abs(F15.ca_‘t’)^p+abs(F34.ca_‘t’)^p+abs(F35.ca_‘t’)^p+abs(F36.ca_‘t’)^p+abs(F37.ca_‘t’)^p)/p
replace loss_‘y’ = L1.loss_‘y’ if missing(loss_‘y’)
drop ca_ln ca_ratio ca_share
}

gen fairness_ideal_‘t’_‘power’ = "tediouseq"
replace fairness_ideal_‘t’_‘power’ = "toilsomeeq" if loss_toilsomeadj < loss_tediousadj
replace fairness_ideal_‘t’_‘power’ =  "timeeq" if loss_timeadj < min(loss_toilsomeadj, loss_tediousadj)
replace fairness_ideal_‘t’_‘power’ = "intdemeq" if loss_intdemadj < min(loss_toilsomeadj, loss_tediousadj, loss_timeadj)
```

```
replace fairness_ideal_`t'_`power' = "prodeq" if loss_prodrel < min(loss_toilsomeadj, loss_tediousadj, loss_timeadj, loss_intdemadj)
replace fairness_ideal_`t'_`power' = "equity" if loss_equity < min(loss_toilsomeadj, loss_tediousadj, loss_timeadj, loss_intdemadj, loss_prodrel)
replace fairness_ideal_`t'_`power' = "equality" if loss_equality < min(loss_toilsomeadj, loss_tediousadj, loss_timeadj, loss_intdemadj, loss_prodrel, loss_equity)

label var fairness_ideal_`t'_`power' `"Fairness-ideal (scenarios 1 and 5)"'
drop loss_equality loss_equity loss_prodrel loss_tediousadj loss_toilsomeadj loss_timeadj loss_intdemadj
}
}



foreach power in 1 2 3 4 {
foreach t in ln ratio share {
foreach y in equality equity prodrel factor1adj factor2adj {

scalar p = `power'
gen ca_ln = ln_comprel - ln_quantrel - ln_`y'
gen ca_ratio = exp(ln_comprel) - exp(ln_quantrel - ln_`y')
gen ca_share = exp(ln_comprel)/(1+exp(ln_comprel)) - exp(ln_quantrel - ln_`y')/(1+exp(ln_quantrel - ln_`y'))
gen loss_`y' = (abs(F1.ca_`t')^p+abs(F3.ca_`t')^p+abs(F5.ca_`t')^p+abs(F7.ca_`t')^p+abs(F9.ca_`t')^p+abs(F11.ca_`t')^p+abs(F13.ca_`t')^p+abs(F15.ca_`t')^p+abs(F34.ca_`t')^p+abs(F35.ca_`t')^p+abs(F36.ca_`t')^p+abs(F37.ca_`t')^p)/p
replace loss_`y' = L1.loss_`y' if missing(loss_`y')
drop ca_ln ca_ratio ca_share
}

gen fairness_ideal2_`t'_`power' = "factor1eq"
replace fairness_ideal2_`t'_`power' = "factor2eq" if loss_factor2adj < loss_factor1adj
```

```
replace fairness_ideal2_`t'_`power' = "prodeq" if loss_prodrel < min(loss_factor1adj, loss_factor2adj)
replace fairness_ideal2_`t'_`power' = "equity" if loss_equity < min(loss_factor1adj, loss_factor2adj, loss_prodrel)
replace fairness_ideal2_`t'_`power' = "equality" if loss_equality < min(loss_factor1adj, loss_factor2adj, loss_prodrel, loss_equity)

label var fairness_ideal2_`t'_`power' `"Fairness-ideal (with factor vars)"'
drop loss_equality loss_equity loss_prodrel loss_factor1adj loss_factor2adj
}
}

drop ln_equality ln_equity

replace qualitysubject = controlquestion_all
label var qualitysubject `"Answered all control questions correctly?"'

***generate indicator variables

gen ind_strictequal = 1-notstrictequalizer
label var ind_strictequal `"Divided50"'
gen ind_controlfalse = 1-controlquestion_all
label var ind_controlfalse `"ControlFalse"'
*label var ind_controlfalse `"Answered at least one control question incorrectly?"'
gen ind_biased = 2-questionnaire1playerremark1
label var ind_biased `"Biased"'
*label var ind_biased `"Have you had the feeling that the questions of the survey were biased?"'
gen ind_confused = 2-questionnaire1playerremark3
label var ind_confused `"Confusing"'
*label var ind_confused `"Did you find any part of this survey confusing?"'
gen ind_bornafter84 = (questionnaire1playerage >=1984)
label var ind_bornafter84 `"BornInAfter84"'
```

```
*label var ind_bornafter84 `"Born in or after 1984?"'
gen ind_female = (questionnaire1playergender == 2)
label var ind_female `"Female"'
*label var ind_female `"Is your gender female?"'
gen ind_bornnotinUSA = (questionnaire1playernationality != "USA")
label var ind_bornnotinUSA `"NotUSA"'
*label var ind_bornnotinUSA `"Not born in the USA?"'
gen ind_belowbachelor = (questionnaire1playerdegree == 1 | questionnaire1playerdegree == 2)
label var ind_belowbachelor `"NoBachelor"'
*label var ind_belowbachelor `"Do you not hold a bachelor (or similar) degree?"'
gen ind_inceabove35 = (questionnaire1playerlabor_income >=7)
label var ind_inceabove35 `"IncomeAbove35k"'
*label var ind_inceabove35 `"Net labor income last year above USD 35000?"'
gen ind_expsmaller10 = (questionnaire1playeramount_surve <= 11)
label var ind_expsmaller10 `"ExpSmaller10"'
*label var ind_expsmaller10 `"Did you participate in ten or less experiments or surveys?"'
gen ind_wagemin = (questionnaire1playersecond_polic >=4)
label var ind_wagemin `"WagesMin"'
*label var ind_wagemin `"The adoption of minimum wages generally leads to more fairness?"'
gen ind_wagemax = (questionnaire1playerthird_policy >=4)
label var ind_wagemax `"WagesMax"'
*label var ind_wagemax `"The adoption of maximum wages generally leads to more fairness?"'
gen ind_wagesubs = (questionnaire1playerfirst_policy >=4)
label var ind_wagesubs `"WageSubs"'
*label var ind_wagesubs `"Wage subsidies on low incomes generally lead to more fairness?"'
gen ind_wagetax = (questionnaire1playerfourth_polic >=4)
label var ind_wagetax `"WageTax"'
*label var ind_wagetax `"Substantial labor taxes on high labor incomes generally lead to more fairness?"'
gen ind_laborvalemp = (questionnaire1playerquestion1 >=4)
label var ind_laborvalemp `"LaborValueemp"'
```

```
*label var ind_laborvalemp `"...the value of the work for the
    employer."'
gen ind_labortedious = (questionnaire1playerquestion2 >=4)
label var ind_labortedious `"LaborTedious"'
*label var ind_labortedious `"...how tedious the work is."'
gen ind_labortoil = (questionnaire1playerquestion3 >=4)
label var ind_labortoil `"LaborToilsome"'
*label var ind_labortoil `"...how toilsome the work is."'
gen ind_laboreduc = (questionnaire1playerquestion4 >=4)
label var ind_laboreduc `"LaborEducation"'
*label var ind_laboreduc `"...the level/amount of education and
    qualification that is necessary for the work."'
gen ind_laborempoff = (questionnaire1playerquestion5 >=4)
label var ind_laborempoff `"LaborEmpoffer"'
*label var ind_laborempoff `"...what the employer offers."'
gen ind_laborhours = (questionnaire1playerquestion6 >=4)
label var ind_laborhours `"LaborHours"'
*label var ind_laborhours `"...the number of working hours."'
gen ind_laborintdem = (questionnaire1playerquestion7 >=4)
label var ind_laborintdem `"LaborIntdem"'
*label var ind_laborintdem `"...how intellectually demanding the
    work is."'
gen ind_laborvalsoc = (questionnaire1playerquestion8 >=4)
label var ind_laborvalsoc `"LaborValuesoc"'
*label var ind_laborvalsoc `"...the value of the work for
    society."'
gen ind_labortalent = (questionnaire1playerquestion9 >=4)
label var ind_labortalent `"LaborTalent"'
*label var ind_labortalent `"...the talent that is necessary for
    the work."'

label define yesno 0 "no" 1 "yes"
label values ind_* yesno

gen ind_quant = (quantrel==0.5)
label var ind_quant `"B quant"'
gen ind_abquant = ind_quant
label var ind_abquant `"B quant"'

```

```
gen ind_quantprime = (quantrel==2)
label var ind_quantprime `"C quant"'
gen ind_acquant = ind_quantprime
label var ind_acquant `"C quant"'

gen ind_prod = (prodrel==0.5)
label var ind_prod `"B prod"'
gen ind_type = not2calc
label var ind_type `"TaDiff"'

foreach x in tedious toilsome time intdem{
gen ind_ac`x'= (ln_`x'adj >0)
label var ind_ac`x' `"C `x'"'
gen ind_ab`x'= (ln_`x'adj <0)
label var ind_ab`x' `"B `x'"'
}

gen ind_sc4 = (scenario_number == 4)
label var ind_sc4 `"Scenario 4"'

gen ind_toilchange = (toilsome_rel < 2 & scenario_number == 4)
label var ind_toilchange `"pos toilchange"'

gen ones = 1
label var ones `"Ones"'

gen zeros = 0
label var zeros `"Zeros"'

***generate auxvars for Conseq, Free Choice, Given Toil

gen comptotal_auxconseq = L16.comptotal
label variable comptotal_auxconseq `"auxiliary var that places
    baseline-comps next to consequential-comps"'
gen compdiff_auxconseq = comptotal - comptotal_auxconseq
label variable compdiff_auxconseq `"auxiliary var computing
    consequential-comps minus baseline-comps"'

gen compshare_auxchoice100 = L23.compshare
```

```
label variable compshare_auxchoice100 `"auxiliary var that places baseline-comps next to 100b100c-freechoice-comps"'
gen compshare_auxchoice200 = L20.compshare
label variable compshare_auxchoice200 `"auxiliary var that places baseline-comps next to 200b100c-freechoice-comps"'
gen compdiff_auxchoice100 = compshare - compshare_auxchoice100
label variable compdiff_auxchoice100 `"auxiliary var computing baseline-comps minus 100b100c-freechoice-comps"'
gen compdiff_auxchoice200 = compshare - compshare_auxchoice200
label variable compdiff_auxchoice200 `"auxiliary var computing baseline-comps minus 200b100c-freechoice-comps"'

gen compensation_diff100 = compensation - L23.compensation
gen compensation_diff200 = compensation - L20.compensation


gen compdiff_auxtoil = comprel - L26.comprel
label variable compdiff_auxtoil `"auxiliary var computing giventoil-comprel minus baseline-comprel"'
gen toildiff_auxtoil = exp(ln_toilsomeadj) - exp(L26.ln_toilsomeadj)
label variable toildiff_auxtoil `"auxiliary var computing giventoil-assessrel minus baseline-assessrel"'


***drop MTurk ID for data protection reason

drop ID



***
save alldata_cleaned.dta, replace
log close _all
```

```
log close _all
clear all
set more off
set graphics off

cd "/home/mv/Dropbox/Raphael-Marius-Ordner/Data" /* path Marius */
log using fairprices_analysis_log.log, replace
use alldata_cleaned.dta

***Fairness ideals & demographics

foreach y in fairness_ideal_ln_1 fairness_ideal_ln_2 fairness_ideal_ln_3 fairness_ideal_ln_4 {
graph bar if cell == "1a_100b100c_rev" & qualitysubject == 1, over(‘y’) name(‘y’, replace) asyvars stack nodraw legend(off) blabel(name, position(center)) allcategories nolabel
}
graph combine fairness_ideal_ln_1 fairness_ideal_ln_2 fairness_ideal_ln_3 fairness_ideal_ln_4,  name(histideals, replace) cols(4) ycommon xcommon imargin(0 0 0 0) commonscheme ysize(10) xsize(30) iscale(*2)
graph export graph_histideals.png, replace width(4000)

foreach x in 1 2 3 4 {
tab fairness_ideal_ln_‘x’ if cell == "1a_100b100c_rev" & qualitysubject == 1
}


foreach y in fairness_ideal2_ln_1 fairness_ideal2_ln_2 fairness_ideal2_ln_3 fairness_ideal2_ln_4 {
graph bar if cell == "1a_100b100c_rev" & qualitysubject == 1, over(‘y’) name(‘y’, replace) asyvars stack nodraw legend(off) blabel(name, position(center)) allcategories nolabel
}
graph combine fairness_ideal2_ln_1 fairness_ideal2_ln_2 fairness_ideal2_ln_3 fairness_ideal2_ln_4,  name(histideals,
```

```
    replace) cols(4) ycommon xcommon imargin(0 0 0 0)
    commonscheme ysize(10) xsize(30) iscale(*2)
graph export graph_histideals2.png, replace width(4000)

foreach x in 1 2 3 4 {
tab fairness_ideal2_ln_`x' if cell == "1a_100b100c_rev" &
    qualitysubject == 1
}


foreach y in controlquestion_all questionnaire1playerremark1
    questionnaire1playerremark3  questionnaire1playergender
    questionnaire1playerdegree questionnaire1playerlabor_income
    questionnaire1playeramount_surve
    questionnaire1playerfirst_policy
    questionnaire1playersecond_polic
    questionnaire1playerthird_policy
    questionnaire1playerfourth_polic
    questionnaire1playerquestion1 questionnaire1playerquestion2
    questionnaire1playerquestion3 questionnaire1playerquestion4
    questionnaire1playerquestion5 questionnaire1playerquestion6
    questionnaire1playerquestion7 questionnaire1playerquestion8
    questionnaire1playerquestion9 {
graph bar if cell == "1a_100b100c_rev",  over(qualitysubject,
    sort(1) descending) over(`y', label(angle(0))) asyvars stack
    name(`y', replace) note("`: var label `y''", span size(small)
    ) legend(off) nodraw label ylabel(0[20]100, angle(0)) ytitle
    ("")
} /* *notstrictequalizer questionnaire1playerage
    questionnaire1playernationality
    questionnaire1playernationality */
graph combine controlquestion_all questionnaire1playerremark1
    questionnaire1playerremark3   questionnaire1playergender
    questionnaire1playerdegree questionnaire1playerlabor_income
    questionnaire1playeramount_surve
    questionnaire1playerfirst_policy
    questionnaire1playersecond_polic
    questionnaire1playerthird_policy
    questionnaire1playerfourth_polic
```

```
questionnaire1playerquestion1 questionnaire1playerquestion2 questionnaire1playerquestion3 questionnaire1playerquestion4 questionnaire1playerquestion5 questionnaire1playerquestion6 questionnaire1playerquestion7 questionnaire1playerquestion8 questionnaire1playerquestion9 , name(descriptivequestionaire , replace) cols(4) ycommon ysize(20) xsize(20)
graph export graph_descriptivequestionaire.png, replace width(4000)

***Assessments

scatter ln_tediousadj ln_intdemadj if abs(ln_tediousadj) <=2 & abs(ln_intdemadj) <=2 & cell == "1a_100b100c_rev" & qualitysubject == 1, yscale(range(-2 2)) xscale(range(2 2)) xline(0) yline(0) xsize(10) ysize(10) jitter(4) name(scatterln1 , replace) nodraw legend(off) msize(tiny)
scatter ln_tediousadj ln_toilsomeadj if abs(ln_tediousadj) <=2 & abs(ln_toilsomeadj) <=2 & cell == "1a_100b100c_rev" & qualitysubject == 1, yscale(range(-2 2)) xscale(range(2 2)) xline(0) yline(0) name(scatterln2 , replace) xsize(10) ysize(10) jitter(4) nodraw legend(off) msize(tiny)
scatter ln_tediousadj ln_timeadj if abs(ln_tediousadj) <=2 & abs(ln_timeadj) <=2 & cell == "1a_100b100c_rev" & qualitysubject == 1, yscale(range(-2 2)) xscale(range(2 2)) xline(0) yline(0) name(scatterln3 , replace) xsize(10) ysize(10) jitter(4) nodraw legend(off) msize(tiny)
graph combine scatterln2 scatterln3 scatterln1 , xcommon ycommon name(scatterassess , replace) xsize(60) ysize(60) altshrink rows(2)
graph export graph_scatterassessln.png, replace width(6000)

hist tedious_rel if cell == "1a_100b100c_rev" & qualitysubject ==1, discrete freq xlabel(0(0.5)4) legend(off) name(histtedious , replace) nodraw
hist intdem_rel if intdem <=4 & cell == "1a_100b100c_rev" & qualitysubject==1, discrete freq xlabel(0(0.5)4) legend(off) name(histintdem , replace) nodraw
```

```
hist toilsome_rel if cell == "1a_100b100c_rev" & qualitysubject==1, discrete freq xlabel(0(0.5)4) legend(off) name(histtoilsome, replace) nodraw
hist time_rel if cell == "1a_100b100c_rev" & qualitysubject==1, discrete freq xlabel(0(0.5)4) legend(off) name(histtime, replace) nodraw
graph combine histtedious histintdem histtoilsome histtime, name(histassessdetail, replace)  xsize(20) ysize(20) ycommon xcommon altshrink rows(2)
graph export graph_histassessdetail.png, replace width(4000)

estpost correlate ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj if cell == "1a_100b100c_rev" & qualitysubject == 1, matrix listwise quietly
esttab using latex_corrln.tex, unstack not nonumbers label noobs compress title("Correlations for log relative assessments \label{tablecorrln}") replace
eststo clear

***Scenarios 1+5: Compensations

hist compensation if ((revision == 1 & scenario_number != 5) | scenario_number == 5 | scenario_number == 3) & fixedpaymessedup != 1 & qualitysubject == 1, discrete name(histcompall, replace) xscale(range(0 1)) percent xtitle("Output distributed to the first worker") ytitle("Percentage of spectators") by(cell, note("") col(4) holes(14, 16)) bcolor(blue) subtitle(, nobexpand)
graph export graph_histcompall.png, replace width(4000)

hist compshare if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1, discrete name(histcomp, replace) xscale(range(0 1)) percent xtitle("Fraction of output distributed to the first worker") ytitle("Percentage of spectators") by(integercell, note("") col(4) iscale(0.55)) bcolor(blue) subtitle(, nobexpand)
graph export graph_histcomp.png, replace width(4000)

***Scenario 2: Consequentialism
```

```

graph twoway (scatter L16.comptotal comptotal  if integercell == 18 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0),  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 40) ) yscale(range(0 40))) (function y = x, range(0 40) legend(off)) (lfit L16.comptotal comptotal  if integercell == 18 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0)), xtitle("100 ball, 100 calc ($0 fixed pay), N=78") ytitle("100 ball, 100 calc ($10 fixed pay)") name(scatterconseq1, replace) nodraw
graph twoway (scatter L16.comptotal comptotal  if integercell == 22 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0),  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 50) ) yscale(range(0 50))) (function y = x, range(0 50) legend(off)) (lfit L16.comptotal comptotal  if integercell == 22 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0)), xtitle("200 ball, 100 calc ($0 fixed pay), N=98") ytitle("200 ball, 100 calc ($10 fixed pay)") name(scatterconseq2, replace) nodraw
graph twoway (scatter L16.comptotal comptotal  if integercell == 20 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0),  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 50) ) yscale(range(0 50))) (function y = x, range(0 50) legend(off)) (lfit L16.comptotal comptotal  if integercell == 20 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0)), xtitle("100 ball, 200 calc ($0 fixed pay), N=100") ytitle("100 ball, 200 calc ($10 fixed pay)") name(scatterconseq3, replace) nodraw
graph twoway (scatter L16.comptotal comptotal  if integercell == 24 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0),  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 60) ) yscale(range(0 60))) (function y = x, range(0 60) legend(off)) (lfit L16.comptotal comptotal  if integercell == 24 & fixedpaymessedup != 1 & qualitysubject == 1 & (compshare !=0.5 | compdiff_auxconseq !=0)), xtitle("200 ball, 200 calc ($0
```

```
fixed pay), N=77") ytitle("200 ball, 200 calc ($10 fixed pay)") name(scatterconseq4, replace) nodraw
graph combine scatterconseq1 scatterconseq2 scatterconseq3 scatterconseq4, name(scatterconseq, replace) xsize(20) ysize(20) altshrink rows(2)
graph export graph_scatterconseq.png, replace width(4000)
graph combine scatterconseq2 scatterconseq3, name(scatterconseqoffdiag, replace) xsize(20) ysize(10) altshrink rows(1)
graph export graph_scatterconseqoffdiag.png, replace width(4000)

hist compdiff_auxconseq if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == 18, discrete name(histconseqdiff1, replace) nodraw xtitle("100 ball, 100 calc (diff in total comp)")
hist compdiff_auxconseq if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == 22, discrete name(histconseqdiff2, replace) nodraw xtitle("200 ball, 100 calc (diff in total comp)")
hist compdiff_auxconseq if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == 20, discrete name(histconseqdiff3, replace) nodraw xtitle("100 ball, 200 calc (diff in total comp)")
hist compdiff_auxconseq if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == 24, discrete name(histconseqdiff4, replace) nodraw xtitle("200 ball, 200 calc (diff in total comp)")
graph combine histconseqdiff1 histconseqdiff2 histconseqdiff3 histconseqdiff4, name(histconseqdiff, replace) xsize(20) ysize(20) altshrink rows(2) ycommon xcommon
graph export graph_histconseqdiff.png, replace width(4000)

matrix CW=J(2,24,.) /*Build Matrix with p-values for ttest, signrank, ksmirnov */
foreach x in 18 22 20 24 {
*quietly ttest comptotal_auxconseq = comptotal if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == `x' & (compshare !=0.5 | compdiff_auxconseq !=0)
*matrix CW[1, `x'] = r(p)
```

```
*quietly signtest comptotal_auxconseq = comptotal if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == `x' & (compshare !=0.5 | compdiff_auxconseq !=0)
quietly signrank comptotal_auxconseq = comptotal if fixedpaymessedup != 1 & qualitysubject == 1 & integercell == `x' & (compshare !=0.5 | compdiff_auxconseq !=0)
*matrix CW[2, `x'] = 2 * normprob(-abs(r(z)))
matrix CW[2, `x'] = r(N_neg) + r(N_pos) + r(N_tie)
quietly ksmirnov comptotal if fixedpaymessedup != 1 & qualitysubject == 1 & (integercell == `x' | integercell == `x'-16) & (compshare !=0.5 | compdiff_auxconseq !=0), by(integercell) exact
matrix CW[1, `x'] = r(p_exact)
}
matrix colnames CW = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 100ball100calc 19 100ball200calc 21 200ball100calc 23 200ball200calc
matrix rownames CW = p-value N
matselrc CW C , r(1/2) c(18, 22, 20, 24)
matrix list C
esttab matrix(C, fmt("4 0")) using latex_pvaluesConseq.tex, mtitles("") nonumbers compress replace

***Scenario 3: Free choice

graph twoway (scatter L23.compshare compshare  if integercell == 25 & qualitysubject == 1,  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 1) ) yscale(range(0 1))) (function y = x, range(0 1) legend(off)) (lfit L23.compshare compshare if integercell == 25 & qualitysubject == 1), xtitle("100 ball, 100 calc (quantity choice), N=242") ytitle("100 ball, 100 calc (no quantity choice)") name(scatterchoice1, replace) nodraw
graph twoway (scatter L20.compshare compshare  if integercell == 26 & qualitysubject == 1,  jitter(4) msize(tiny) xsize(10) ysize(10) xscale(range(0 1) ) yscale(range(0 1))) (function y = x, range(0 1) legend(off)) (lfit L20.compshare compshare if integercell == 26 & qualitysubject == 1), xtitle("200 ball, 100 calc (quantity choice), N=242") ytitle("200 ball, 100
```

```
calc (no quantity choice)") name(scatterchoice2, replace) nodraw
graph combine scatterchoice1 scatterchoice2, name(scatterchoice, replace) xsize(20) ysize(10) altshrink
graph export graph_scatterchoice.png, replace width(4000)

hist compdiff_auxchoice100 if qualitysubject == 1 & integercell == 25, discrete name(histchoicediff1, replace) nodraw xtitle("100 ball, 100 calc (diff in compshare)")
hist compdiff_auxchoice200 if qualitysubject == 1 & integercell == 26, discrete name(histchoicediff2, replace) nodraw xtitle("200 ball, 100 calc (diff in compshare)")
graph combine histchoicediff1 histchoicediff2, name(histchoicediff, replace) xsize(20) ysize(10) altshrink ycommon xcommon
graph export graph_histchoicediff.png, replace width(4000)

hist compensation_diff100 if qualitysubject == 1 & integercell == 25 & (compensation !=15 | L23.compensation !=10), discrete name(histchoicediffx1, replace) nodraw
hist compensation_diff200 if qualitysubject == 1 & integercell == 26 & (compensation !=20 | L23.compensation !=15), discrete name(histchoicediffx2, replace) nodraw
graph combine histchoicediffx1 histchoicediffx2, name(histchoicediffx, replace) xsize(20) ysize(10) altshrink ycommon xcommon
graph export graph_histchoicediffx.png, replace width(4000)

matrix F=J(2,2,.) /*Build Matrix with p-values for ttest, signrank, ksmirnov */
*quietly ttest compshare_auxchoice100 == compshare if qualitysubject == 1 & integercell == 25
*matrix F[1, 1] = r(p)
*quietly ttest compshare_auxchoice100 == compshare if qualitysubject == 1 & integercell == 26
*matrix F[1, 2] = r(p)
quietly signrank compshare_auxchoice100 = compshare if qualitysubject == 1 & integercell == 25
matrix F[1, 1] = 2 * normprob(-abs(r(z)))
```

```
quietly signrank compshare_auxchoice100 = compshare if qualitysubject == 1 & integercell == 26
matrix F[1, 2] = 2 * normprob(-abs(r(z)))
quietly ksmirnov compshare if qualitysubject == 1 & (integercell == 25 | integercell == 2), by(integercell) exact
matrix F[2, 1] = r(p_exact)
quietly ksmirnov compshare if qualitysubject == 1 & (integercell == 26 | integercell == 6), by(integercell) exact
matrix F[2, 2] = r(p_exact)
matrix colnames F = 100b100c 200b100c
matrix rownames F = WilcoxonSignedrank p-value
matrix list F
esttab matrix(F, fmt(4)) using latex_pvaluesFreeChoice.tex, replace


eststo: quietly reg ln_comprel scenario_number##(c.ln_quantrel c.ln_tediousadj c.ln_toilsomeadj c.ln_timeadj c.ln_intdemadj) if ((scenario_number == 1 & revision == 1 & calctask == 100 & prodrel == 1) | (scenario_number == 3)) & qualitysubject==1, vce(cluster integerID)
esttab est1 using latex_regressionssc3.tex, se wide stats(N, fmt(0)) title("Regressions for Scenarios 1(i) and 3\label{tableregressionssc3}") nonumbers replace interaction(" $\times$ ")style(tex) label nogaps mtitles("Sc1+Sc3") nobaselevels compress order(_cons ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj) b(2) noomitted addnote("s.e. clustered at individual level")
eststo clear

gen compSc3diff = compensation - L23.compensation if integercell==25
replace compSc3diff = compensation - L20.compensation if integercell==26
estpost tab compSc3diff integercell if qualitysubject==1
esttab . using latex_sc3interior.tex, cells("pct(fmt(2))") noobs unstack compress title("Distribution of additional output in Scenario 3 \label{tableSc3}") collabels(none) replace
eststo clear
```

```
***Dummy-Regressions

eststo: quietly reg ln_comprel ind_prod ind_acquant ind_abquant
    ind_actedious ind_abtedious ind_actoilsome ind_abtoilsome
    ind_actime ind_abtime ind_acintdem ind_abintdem if ((
    scenario_number == 1 & revision == 1) | scenario_number == 5)
     & qualitysubject==1, vce(cluster integerID)
foreach y in quant tedious toilsome time intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant
    ind_abquant ind_actedious ind_abtedious ind_actoilsome
    ind_abtoilsome ind_actime ind_abtime ind_acintdem
    ind_abintdem if ((scenario_number == 1 & revision == 1) |
    scenario_number == 5) & qualitysubject==1 ||  integerID:
    ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious
    ind_actoilsome ind_abtoilsome ind_actime ind_abtime
    ind_acintdem ind_abintdem , vce(cluster integerID) stddev
    iterate(100)
foreach y in quant tedious toilsome time intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant
    ind_abquant ind_actedious ind_abtedious ind_actoilsome
    ind_abtoilsome ind_actime ind_abtime ind_acintdem
    ind_abintdem i.ind_belowbachelor##(i.ind_prod i.ind_acintdem
    i.ind_abintdem) if ((scenario_number == 1 & revision == 1) |
    scenario_number == 5) & qualitysubject==1  ||  integerID:
    ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious
    ind_actoilsome ind_abtoilsome ind_actime ind_abtime
    ind_acintdem ind_abintdem , vce(cluster integerID) stddev
    iterate(100)
foreach y in quant tedious toilsome time intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
```

```
eststo: quietly mixed ln_comprel ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious ind_actoilsome ind_abtoilsome ind_actime ind_abtime ind_acintdem ind_abintdem i.ind_inceabove35##(i.ind_prod i.ind_acintdem i.ind_abintdem) if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1  ||  integerID: ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious ind_actoilsome ind_abtoilsome ind_actime ind_abtime ind_acintdem ind_abintdem , vce(cluster integerID) stddev iterate(100)
foreach y in quant tedious toilsome time intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious ind_acintdem ind_abintdem if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 ||  integerID: ind_prod ind_acquant ind_abquant ind_actedious ind_abtedious ind_acintdem ind_abintdem, vce(cluster integerID) stddev iterate(100)
foreach y in quant tedious intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant ind_abquant ind_actoilsome ind_abtoilsome ind_acintdem ind_abintdem if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 ||  integerID: ind_prod ind_acquant ind_abquant ind_actoilsome ind_abtoilsome ind_acintdem ind_abintdem, vce(cluster integerID) stddev iterate(100)
foreach y in quant toilsome intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant ind_abquant ind_actoilsome ind_abtoilsome ind_acintdem ind_abintdem ind_toilchange if ((scenario_number == 1 &
```

```
revision == 1) | (scenario_number == 4 & revision == 1) |
scenario_number == 5) & qualitysubject==1 ||  integerID:
ind_prod ind_acquant ind_abquant ind_actoilsome
ind_abtoilsome ind_acintdem ind_abintdem , vce(cluster
integerID) stddev iterate(100)
foreach y in quant toilsome intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
eststo: quietly mixed ln_comprel ind_prod ind_acquant
ind_abquant ind_actime ind_abtime ind_acintdem ind_abintdem
if ((scenario_number == 1 & revision == 1) | scenario_number
== 5) & qualitysubject==1 ||  integerID: ind_prod ind_acquant
 ind_abquant ind_actime ind_abtime ind_acintdem ind_abintdem,
 vce(cluster integerID) stddev iterate(100)
foreach y in quant time intdem{
quietly test ind_ac`y' - ind_ab`y' =0
estadd scalar p_`y' = r(p)
}
esttab est1 est2 est3 est4 est5 est6 est7 est8 using
latex_regressionsdummy.tex, not stats(p_quant p_tedious
p_toilsome p_time p_intdem N, fmt (3 3 3 3 3 0)) title("
Regressions with dummy regressors [sd assignment wrong;
insert h and v lines]\label{tableregressionsdummy}") addnote
("Standard errors clustered at individual level; for \emph{
base}, \emph{$<$ ba}, \emph{$\geq$ 35k}, significance of sd($
\cdot$) was not computable")  nonumbers replace interaction("
 $\times$ ")style(tex) label nogaps mtitles("ols" "base" "$<$
 ba" "$\geq$ 35k" "tedious" "toil" "+Sc4" "time")
nobaselevels drop(1.ind_prod 1.ind_acintdem 1.ind_abintdem)
compress order(_cons ind_prod ind_acquant ind_abquant
ind_actedious ind_abtedious ind_actoilsome ind_abtoilsome
ind_actime ind_abtime ind_acintdem ind_abintdem) transform(
lns*: exp(@) exp(@)) b(2) eqlabels("" "sd(B prod)" "sd(C
quant)" "sd(B quant)" "sd(C tedious)" "sd(B tedious)" "sd(C
toilsome)" "sd(B toilsome)" "sd(C time)" "sd(B time)" "sd(C
intdem)" "sd(B intdem)" "sd(Constant)" "sd(Residual)", none)
eststo clear

```

```
***Log-Regressions

eststo: quietly reg ln_comprel ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1, vce(cluster integerID)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj, vce(cluster integerID) stddev iterate(100)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj ind_belowbachelor##(c.ln_prodrel c.ln_intdemadj) if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj, vce(cluster integerID) stddev iterate(100) coefleg
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj ind_inceabove35##(c.ln_prodrel c.ln_intdemadj) if ((scenario_number == 1 & revision == 1) | scenario_number == 5) &qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj, vce(cluster integerID) stddev iterate(100)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_tediousadj ln_intdemadj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_tediousadj ln_intdemadj, vce(cluster integerID) stddev iterate(100)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_toilsomeadj ln_intdemadj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_toilsomeadj ln_intdemadj, vce(cluster integerID) stddev iterate(100)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_toilsomeadj ln_intdemadj ind_toilchange if ((scenario_number == 1 & revision == 1) | (scenario_number == 4
```

```
& revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_toilsomeadj ln_intdemadj , vce(cluster integerID) stddev iterate(100)
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_timeadj ln_intdemadj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_timeadj ln_intdemadj, vce(cluster integerID) stddev iterate(100)
esttab est1 est2 est3 est4 est5 est6 est7 est8 using latex_regressionslog.tex, not stats(N, fmt (0)) title("Regressions with log regressors [sd assignment wrong; insert h and v lines]\label{tableregressionslog}") addnote("S.e. clustered at individual level; for \emph{base} and \emph{$\geq$ 35k}, significance of sd($\cdot$) was not computable") nonumbers replace interaction(" $\times$ ")style(tex) label nogaps mtitles("ols" "base" "$<$ ba" "$\geq$ 35k" "tedious" "toil" "+Sc4" "time") nobaselevels compress order(_cons ln_prodrel ln_quantrel ln_tediousadj ln_toilsomeadj ln_timeadj ln_intdemadj) transform(lns*: exp(@) exp(@)) b(2) eqlabels("" "sd(lnprod)" "sd(lnquant)" "sd(lntedious)" "sd(lntoilsome)" "sd(lntime)" "sd(lnintdem)" "sd(Constant)" "sd(Residual)", none) noomitted
eststo clear

***factor analysis
eststo: quietly mixed ln_comprel ln_prodrel ln_quantrel ln_factor1adj ln_factor2adj if ((scenario_number == 1 & revision == 1) | scenario_number == 5) & qualitysubject==1 || integerID: ln_prodrel ln_quantrel ln_factor1adj ln_factor2adj, vce(cluster integerID) stddev iterate(100)
esttab est1 using latex_regressionsfactor.tex, se wide stats(N, fmt (0)) title("Regressions with factor variables\label{tableregressionsfactor}") addnote("S.e. clustered at individual level") nonumbers replace style(tex) label nogaps nobaselevels compress order(_cons ln_prodrel ln_quantrel ln_factor1adj ln_factor2adj) transform(lns*: exp(@) exp(@)) b(2) eqlabels("" "sd(lnprod)" "sd(lnquant)" "sd(lnfactor1)" "sd(lnfactor2)" "sd(Constant)" "sd(Residual)", none) noomitted
eststo clear
```

```
***
log close _all
```

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