

**Beyond Baseline and Follow-up:
The Case for More T in Experiments***

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Abstract

The vast majority of randomized experiments in economics rely on a single baseline and single follow-up survey. If multiple follow-ups are conducted, the reason is typically to examine the trajectory of impact effects, so that in effect only one follow-up round is being used to estimate each treatment effect of interest. While such a design is suitable for study of highly autocorrelated and relatively precisely measured outcomes in the health and education domains, this article makes the case that it is unlikely to be optimal for measuring noisy and relatively less autocorrelated outcomes such as business profits, household incomes and expenditures, and episodic health outcomes. Taking multiple measurements of such outcomes at relatively short intervals allows one to average out noise, increasing power. When the outcomes have low autocorrelation, it can make sense to do no baseline at all. Moreover, I show how for such outcomes, more power can be achieved with multiple follow-ups than allocating the same total sample size over a single follow-up and baseline. I also highlight the large gains in power from ANCOVA analysis rather than difference-in-differences analysis when autocorrelations are low and a baseline is taken. This article discusses the issues involved in multiple measurements, and makes recommendations for the design of experiments and related non-experimental impact evaluations.

Keywords: Randomized Experiments; Multiple Measurements; Program Evaluation.

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1. Introduction

The number of randomized experiments being conducted in economics has exploded over the past decade, especially in development economics. The vast majority of these studies use only a single baseline and single follow-up survey, or a single follow-up with no baseline. This has been the case in the early randomized experiments looking at education (e.g. Glewwe et al, 2004) and health outcomes (e.g. Miguel and Kremer, 2004), and has remained true as experiments have expanded to consider other interventions and outcomes, such as recent high-profile experiments in microfinance (Karlan and Zinman, 2010; Banerjee et al, 2010). In the rare cases where multiple post-treatment survey waves have been conducted, they have been typically taken relatively far apart in time, with the goal of examining whether the treatment effect differs in the short-term and medium-term. For example, Banerjee et al. (2007) examine impacts of educational interventions at one year and two year horizons. Indeed, so much is the paradigm of baseline plus follow-up accepted that the excellent toolkit for randomization of Duflo et al. (2008) does not discuss at all the possibility of doing more than one pre-treatment or post-treatment round of surveying, let alone the choice of how many such rounds.

In contrast, the clinical trials literature has noted the potential advantages of taking repeated measures of outcomes of interest not just to study the time course of treatment effects, but to obtain more precise estimates of effects around particular endpoints (Frison and Pocock, 1992). Vickers (2003) argues that the number of repeat measures should be a key design choice in conducting experiments, and concludes that the benefit of such additional measures is of greatest value when the autocorrelation of measures is low, such as with episodic conditions like headaches. Such a description would certainly seem to fit key economic outcomes like business profits, and incomes and consumption of the poor. As the recent work by Collins et al. (2009) makes abundantly clear, one of the key difficulties of living on \$2 a day is that people don't receive \$2 every day, but rather a highly irregular stream of income. Measuring microenterprise income, in particular, can be difficult, with the resulting data typically having large heterogeneity in reported profits among reasonably similarly sized firms (de Mel et al, 2009). While some of this likely reflects measurement error, Fafchamps et al. (2010a) report that Ghanaian microenterprise owners confirm 85 percent or more of changes in profits above 150 percent or below -60 percent as genuine, reflecting seasonality and the high degree of idiosyncratic variability facing microenterprise owners.

As a result of the high variability and low autocorrelation in economic outcomes like firm profits, income, and expenditure among poor households, there is much to be potentially gained by taking multiple measures of these outcomes at relatively short intervals and averaging over them when estimating treatment effects. This is the approach used in de Mel et al. (2008), who use a baseline and 8 quarterly follow-up waves of business profits and in Fafchamps et al. (2010)

which uses two survey rounds before randomization and a further 4 quarterly follow-up surveys.¹ However, this approach seems to be the exception rather than the rule. This paper aims to combine insights from the medical literature on repeated measurement, new analysis of the formulae underlying power calculations, and experience from these studies using multiple measures in economics to provide a practical guide for researchers designing experiments. While our discussion will be in terms of experiments, many of the same issues and therefore lessons also apply for design of non-experimental impact evaluation designs, such as matched difference-in-difference estimation.²

An additional contribution of the paper is to draw to the attention of empirical researchers in economics the large improvement in power than can arise when estimating treatment effects via an Analysis of Covariance (ANCOVA) estimation compared to using the more common difference-in-difference specification. The improvement in power is greatest when the autocorrelation is low – intuitively when the baseline data have little predictive power for future outcomes, it is inefficient to fully correct for baseline imbalances between treatment and control groups.

Section 2 begins with a theoretical discussion of what power calculations tell us about the gain to be had from using more rounds of data, and provides examples for common types of economic data. Section 3 then derives implications for the choice of how many pre-treatment and post-treatment waves to use. The bottom line is that collecting multiple measurements post-treatment will make most sense when the data have low autocorrelation; whereas baseline data is of most use when the autocorrelation is high (although there are of course other important uses of baseline data apart from improving the power to estimate treatment effects, such as for examining treatment heterogeneity, and so one may still wish to do a baseline for these other reasons – something I discuss at the end of the paper). It would appear that for many economic outcomes, experiments with a fixed budget to conduct a total of K surveys would have greater power when dividing that K over multiple post-treatment rounds than having a baseline and single follow-up. Section 4 then discusses additional practical issues which are likely to arise when considering multiple measurements in economic experiments, many of which are not common concerns in clinical trials. Section 5 concludes.

¹ Bloom et al. (2010) provides an example of very large T , with 114 weekly observations on firm output, quality, and inventory levels.

² Gibson and McKenzie (2010) provide an example where multiple rounds of follow-up data are averaged to get more precise measurements of consumption and income in a matched difference-in-differences impact evaluation of a seasonal migration program. One key difference with non-experimental evaluations is that the presence of a baseline becomes more valuable to allow one to control for baseline differences across individuals; whereas randomization ensures these baseline differences are balanced on average.

2. What is the gain from more rounds?

Let $Y_{i,t}$ be an outcome of interest for household or firm i in survey round t . Consider an intervention which assigns units to receive a binary treatment (such as getting business training or not, or getting a conditional cash transfer or not). Suppose there are m pre-treatment survey rounds (labeled $-(m-1)$ through 0) and r post-treatment survey rounds (labeled 1 through r). A common method in economics for estimating the treatment effect³ of the intervention on the outcome of interest is via the following difference-in-differences specification:

$$Y_{i,t} = \beta EVERTREAT_i + \sum_{t=-(m-1)}^r \delta_t + \gamma TREAT_{i,t} + \varepsilon_{i,t} \quad (1)$$

where $EVERTREAT_i$ is a dummy variable which takes value one if unit i is assigned to the treatment group and zero if it is assigned to the control group, the δ_t are time dummies, and $TREAT_{i,t}$ takes value one if unit i has been assigned to receive treatment by time t (that is for $t=1,2,\dots,r$), and zero otherwise. The treatment effect of interest is then given by γ .

Note that γ does not contain a t subscript: either the treatment is assumed to have a constant level effect, or the treatment effect of interest is taken to be the average treatment effect over the r post-treatment rounds. The last section of the paper discusses how to apply the insights of this paper when one is interested in examining the dynamics of the treatment effect.

2.1. The case of a single baseline and single follow-up

Consider first the case of a single baseline and single follow-up. Then we see that the least squares estimator of γ is simply the difference in means between the treatment and control groups at follow-up less the difference in means between the treatment and control groups at baseline:

$$\hat{\gamma}_{DD} = (\bar{Y}_1^T - \bar{Y}_1^C) - (\bar{Y}_0^T - \bar{Y}_0^C) \quad (2)$$

Then sample size to detect a given treatment effect at a specified power level and significance level is a linear function of the variance of this estimator. Assume the $\varepsilon_{i,t}$ are independent across individual units with cross-sectional variance σ^2 , but may be autocorrelated over time for the same unit, with autocorrelation ρ . The variance of the difference-in-differences estimator is then easily seen to be $4\sigma^2(1-\rho)/n$ where n is the size of the treatment and control groups. Compare this to the simple ‘‘post’’ estimator, which uses only the difference in means for the follow-up survey, ignoring the baseline:

$$\hat{\gamma}_{POST} = (\bar{Y}_1^T - \bar{Y}_1^C) \quad (3)$$

which has variance $2\sigma^2/n$. From this we observe the following:

³ I focus on estimation of intention-to-treat effects here, but the same points made here also apply for measurement of the treatment effect on the treated and other treatment effects of interest.

Fact 1: With a single baseline and follow-up, difference-in-differences only gives more power than the post estimator which ignores the baseline data when the autocorrelation is greater than 0.5.

A more efficient method of estimation than difference-in-differences is to control for the baseline levels of the outcome of interest and estimate the following⁴:

$$Y_{i,1} = \alpha + \gamma TREAT_{i,1} + \theta Y_{i,0} + \varepsilon_{i,1} \quad (4)$$

Let $\hat{\theta}$ be the least squares estimator of θ , then the estimator of the treatment effect coming from equation (4) is called the ANCOVA estimator

$$\hat{\gamma}_{ancova} = (\bar{Y}_1^T - \bar{Y}_1^C) - \hat{\theta}(\bar{Y}_0^T - \bar{Y}_0^C) \quad (5)$$

Frison and Pocock (1992) show that ANCOVA is more efficient than either difference-in-differences or analysis using only the post data, with a variance proportional to $2\sigma^2(1-\rho^2)/n$. We therefore deduce:

Fact 2: When the data have zero autocorrelation, there is no gain from using baseline data. Otherwise the ANCOVA estimation in equation (4) offers more power than either the commonly used difference-in-differences estimation or estimation based on follow-up.

Intuitively, when the autocorrelation is low, the baseline data are not very informative for what future values of the outcome of interest will be. Controlling fully for observed baseline differences in the mean outcome via difference-in-differences is therefore over-correcting for differences which don't have much predictive power, whereas the ANCOVA estimation adjusts the degree of correction for baseline differences in means according to the degree of correlation between past and future outcomes actually observed in the data.

The ratio of the difference-in-differences variance to the ANCOVA variance is $2/(1+\rho)$. So when $\rho=0$, with a single baseline and follow-up, one would need twice the sample size when using difference-in-differences to get the same power as obtained with ANCOVA. When $\rho=0.25$, which we will see to be a reasonable estimate for several economic outcomes, the sample size needed is still 60% higher with difference-in-differences than with ANCOVA to get the same power. There are therefore important gains in power to be had from not using difference-in-differences to estimate treatment effects with standard economic variables.

2.2. Multiple rounds pre- or post-treatment.

Now consider the general case of m pre-treatment survey rounds and r post-treatment survey rounds. The difference-in-differences estimator is obtained by estimation of equation (1). This can be written as:

⁴ Such a specification is estimated in Banerjee et al. (2007) among others.

$$\hat{\gamma}_{DD} = (\bar{Y}_{POST}^T - \bar{Y}_{POST}^C) - (\bar{Y}_{PRE}^T - \bar{Y}_{PRE}^C) \quad (6)$$

Where for $g \in \{T, C\}$

$$\bar{Y}_{POST}^g = \frac{1}{r} \sum_{t=1}^r \bar{Y}_t^g = \frac{1}{rn} \sum_{t=1}^r \sum_{i=1}^n Y_{i,t}^g$$

is the mean of the outcome for treatment or control group g in the post-treatment period, and n is the number of cross-sectional observations assigned to treatment and to control. The pre-treatment means \bar{Y}_{PRE}^T are defined \bar{Y}_{PRE}^C analogously.

Frison and Pocock (1992) give a general formula for the variance of $\hat{\gamma}_{DD}$, which depends on the full pattern of autocorrelations across the different time periods. For power calculations, one needs to make simplifying assumptions as to how these autocorrelations behave. Frison and Pocock assume equal variances for all time points, equal correlations between all pairs of time points, and that autocorrelations are equal for the treatment and control groups. They show for physical health measures like cholesterol, blood pressure, and CD₄ cell count that this assumption of constant autocorrelation is reasonable. In the next subsection I show such an assumption may also hold approximately for key economic outcomes. Then assuming the treatment and control groups are each of cross-sectional size n , the variance of the difference-in-differences estimator is shown by Frison and Pocock to be:

$$\frac{2\sigma^2}{n} \left[\frac{1 + (r-1)\rho}{r} - \frac{(m+1)\rho - 1}{m} \right] \quad (7)$$

Under these same assumptions, the variance without any baseline surveys of the difference in post-treatment means is then:

$$\frac{2\sigma^2}{n} \left[\frac{1 + (r-1)\rho}{r} \right] \quad (8)$$

Equations (7) and (8) are respectively the variances used in power calculations under the ‘‘POST’’ and ‘‘CHANGE’’ methods reported in STATA’s *sampsi* command. We therefore see that:

Fact 3: With m baselines and r follow-ups, difference-in-differences only gives more power than the post estimator which ignores the baseline data when the autocorrelation is greater than $1/(m+1)$.

Not surprisingly, fact 3 shows that the more baseline rounds of data there are, the more likely it is that it is costly to ignore them. However, as with the single baseline case, if the data are only weakly autocorrelated, it can be costly in terms of power to fully control for baseline differences in means via difference-in-differences.

As with the single baseline and follow-up case, ANCOVA estimation will be more efficient than both difference-in-differences and estimation using only the follow-up data. The ANCOVA estimator with multiple pre- and post-treatment rounds is:

$$\hat{\gamma}_{ancova} = (\bar{Y}_{POST}^T - \bar{Y}_{POST}^C) - \hat{\theta}(\bar{Y}_{PRE}^T - \bar{Y}_{PRE}^C) \quad (9)$$

This can be estimated via the following least squares regression for $t=1,2,\dots,r$ for individual i :

$$Y_{i,t} = \sum_{t=1}^r \delta_t + \gamma TREAT_{i,t} + \theta \bar{Y}_{i,PRE} + \varepsilon_{i,t} \quad (10)$$

where $\bar{Y}_{i,PRE}$ is the mean for individual i over the m pre – treatment rounds. It is very rare for economists to collect more than one round of data pre-treatment, so such an equation has not been typically estimated in practice for more than one pre-treatment round.

Under the same assumptions as used to derive (7) and (8), the variance of the ANCOVA estimation is then approximately:

$$\frac{2\sigma^2}{n} \left[\frac{1 + (r - 1)\rho}{r} - \frac{m\rho^2}{1 + (m - 1)\rho} \right] \quad (11)$$

This is the formula used in power calculations under the ANCOVA option using STATA's `sampsi` command.

Fact 4: If the autocorrelation is zero, then only the number of post-treatment survey waves affects the power of the ANCOVA estimator, there is no gain from baseline surveys, and it reduces to the POST estimator. Intuitively, an autocorrelation of zero means that each round the outcome is a mean plus noise. The treatment changes the mean, and more post-treatment rounds enables one to better average out this noise.

2.3 What are the autocorrelations like for economic data?

As noted above, the formulae for the variances of the different estimators assume that the autocorrelations are equal between all points in time, and that they are equal for the treatment and control groups. To investigate whether this is a reasonable approximation, Table 1 provides the autocorrelations between different survey rounds for some key economic outcomes of interest. I begin with data on microenterprise profits and on household expenditure from the Ghana Microenterprise Survey and experiment of Fafchamps et al. (2010b). I show both levels

and logs, since researchers may use either as an outcome measure. I then only show profits from the Sri Lankan microenterprises in de Mel et al. (2008), since this study only collected expenditure annually.

We see first that the autocorrelations are typically less than 0.5, especially when levels are used instead of logs. The average autocorrelation for profits is 0.30 in the Ghanaian data and 0.42 in the Sri Lankan data for the control groups, while the average autocorrelation is 0.24 for household expenditure. Second, the assumption that the autocorrelations are equal between all points in time, while clearly not holding exactly, appears to be a reasonable first-order approximation. For example, log profits for the control group in Ghana has a correlation with the first round profits ranging between 0.39 for the sixth survey wave and 0.47 in the third wave. Gibson et al. (2003) also provide evidence from Zambia and urban China that the autocorrelation of expenditure does not change very much within a year as one increases the number of months between surveys. The assumption that the treatment and control groups have the same autocorrelations appears to a first-order reasonable in Sri Lanka, but is less the case with profits in Ghana. Nonetheless, for the purpose of getting rough magnitudes of sample sizes needed in power calculations, assuming the autocorrelation is stable doesn't seem too bad.

What should one do if the autocorrelations are not constant? For post and difference-in-difference analysis, one can simply use the mean autocorrelation in the power calculations. Since the variances of these estimators are linear in ρ , power calculations using the mean ρ will still give the correct power for these estimators even when the autocorrelation differs between treatment and control groups or over different time periods. In contrast, since the variance of the ANCOVA estimate is decreasing in ρ^2 , using the average ρ will understate the sample size one would actually need to achieve a given power. In such cases using the minimum ρ expected among follow-up rounds would be conservative.

A final point to note from Table 1 is that the autocorrelations between periods 2 and future periods are typically higher than those between periods 1 and future periods. This is consistent with the view that, at least when it comes to thinking about and recalling items like business profits and expenditures, individuals may get better at understanding the questions after a round or two of data collection (Fafchamps et al, 2010a). This provides a practical reason to consider one or more baseline surveys, even if the baseline survey data are not in of themselves that directly useful for improving power.

Table 2 provides autocorrelations from other data sets for a range of different economic outcomes. The purpose of this is twofold. First, it demonstrates that for many economic outcomes, the autocorrelations are typically lower than 0.5, with many around 0.3. An exception is test scores, which have higher autocorrelations.⁵ Second, it provides some parameters that

⁵ The autocorrelations for the test score data from Banerjee et al. (2007) are similar for treatment and control, providing another data point to suggest that the assumption of the treatment not affecting the autocorrelation is likely to be a useful approximation for many economic experiments. For example, the verbal test score autocorrelation is

researchers can use when conducting their own power calculations, since it is rare to have autocorrelation data available for the study populations being considered. We see from Table 2 that autocorrelations are often in the 0.2-0.3 range for household income and consumption. In rural Ghana, the autocorrelation in Boozer et al (2010)'s data is 0.32 when wives report on both their own and their husband's consumption, but increase to 0.58 to 0.66 when husbands and wives report separately on consumption and the results are combined. The autocorrelations are lower for the poor – in both Mexico and Argentina the autocorrelation of labor income is around 0.2-0.3 for individuals with first period labor income below the median, compared to autocorrelations of 0.5-0.8 for those with this income above the median.

3. Implications for choosing the number of pre-treatment and post-treatment rounds

Equations (7), (8) and (11) can be used to help researchers decide how many rounds of data they should collect before and after the treatment. We use these formulae to examine implications for choice of the number of pre-treatment and post-treatment rounds.

3.1. Given a fixed T of 3 or more rounds, how should they be split between pre-treatment and post-treatment?

The first question we ask is how a researcher who has decided on fielding multiple survey rounds should split these rounds before and after treatment. To do this, we solve for the choice of r and m which minimizes the variance given $r+m=T$.

Fact 5: The optimal choice of $r = T/2 = m$ for difference-in-differences estimation, and this choice does *not* depend on the autocorrelation in the data. When $T \geq 3$ is odd, the power is the same when choosing $m-r=1$ as $r-m=1$, that is, when allocating the extra odd wave to pre-treatment or to post-treatment.

Proof: Setting $r+m=T$ in equation (7) and solving for the optimal choice of r to minimize the variance gives the first part of this result. Re-writing the variance in (7) as

$$\frac{2\sigma^2}{n} \left[\frac{(r+m)(1-\rho)}{rm} \right] \quad (12)$$

Shows that r and m contribute symmetrically to the variance of the difference-in-differences estimator, and so that choosing $r = (T+1)/2$ and $m=(T-1)/2$ will yield the same results as choosing $r=(T-1)/2$ and $m=(T+1)/2$

Intuitively, in a difference-in-differences design, differences in pre-treatment means have exactly as much weight in the estimator as differences in post-treatment means, and so the optimal strategy is to have the same number of time periods to estimate the difference pre-treatment as

0.58 for the treatment group and 0.61 for the control group; and the math test score autocorrelation is 0.47 for the treatment group and 0.55 for the control group.

post-treatment. Note from (12) that while the autocorrelation does not affect the choice of how to allocate the survey rounds between pre-treatment and post-treatment in a difference-in-differences design, it does affect the cross-sectional sample size needed – a higher autocorrelation reduces the variance, thereby requiring a smaller n .

Fact 6: For ANCOVA estimation, the optimal choice of r given fixed T is given by

$$r = \frac{1 + \rho(T - 1)}{2\rho} \quad (13)$$

So when $\rho=0.5$, the optimal choice is $r = (T+1)/2$, whereas when $\rho=0.25$, the optimal choice of $r = (T+3)/2$.

Proof: Expanding out the variance in (11), one sees that r and m are symmetric in the numerator. Minimizing the variance therefore amounts to maximizing the denominator, $r[1+(m-1)\rho]$, which can be solved to give the expression in (13).

Thus with ANCOVA estimation, one chooses fewer pre-treatment survey rounds the lower is the autocorrelation. Intuitively, we see in equation (9) that the pre-treatment difference in means contributes less to the estimator than the post-treatment difference in means, and so it is less important to accurately measure the pre-treatment difference than to accurately measure the post-treatment difference. When the autocorrelation is low, this can result in choosing to have no baseline. For example, when $T=3$ and $\rho=0.25$, the optimal choice is $r=3$, so one is better to have 3 follow-up waves and no baseline than a baseline and two follow-up waves.

3.2 Given a fixed total sample size nT , what is the trade-off between a larger cross-section and more survey rounds?

In many cases a researcher will face a fixed total budget, which can fund $K=nT$ total surveys. They must then decide between carrying out a larger cross-sectional sample, which gives information on more units, and carrying out more survey rounds, which gives more information on each unit. Taking K as fixed, we derive the optimal division into more rounds versus more individuals per round.

Fact 7: For POST estimation, the optimal choice is $T=1$ and $n=K$ when $\rho>0$, and all values of T and n such that $nT=K$ yield the same power when $\rho=0$. When $\rho<0$, the power is higher using $T=2$ and $n=K/2$ than it is using $T=1$ and $n=K$, while the assumption of constant autocorrelation across different points in time doesn't make sense for negative autocorrelation and $T>2$.

Proof: From equation (8) we can see that when $rn=K$, the variance depends on $(r-1)\rho$, so the optimal choice of r to minimize this will depend on ρ in the way stated.

This fact is analogous to the decision in a clustered randomized trial of whether to collect more observations per cluster, or more clusters. With clustered randomization, since randomization is

at the level of the cluster, if there is positive intra-cluster correlation, there is more power to be had in randomizing over more clusters than in having fewer clusters and a larger sample per cluster. Likewise here the randomization occurs in the cross-section, and so with positive autocorrelation, there is more gain to having more cross-sectional units than more observations in the time dimension on each unit.

Fact 8: For difference-in-differences estimation, the choice of how to allocate a fixed sample K between n and T does not affect the variance provided that one then chooses to allocate T equally between pre-treatment and post-treatment rounds (as in Fact 5), and that there is at least one baseline and one follow-up to enable difference-in-differences estimation.

Proof: Setting $r=m=T/2$ and $nT=K$ in (12) yields a variance of $8\sigma^2(1-\rho)/K$ which does not depend on either T or n .

Thus the power of difference-in-differences estimation is the same with a single baseline and follow-up and $n=100$, as it is with two pre-treatment rounds and two post-treatment rounds and $n=50$. Intuitively, with difference-in-differences, every observation counts equally in calculating the pre-treatment and post-treatment means which form the basis of estimation.

Fact 9: With ANCOVA estimation, when the autocorrelation is high it is better to do a larger cross-section and fewer survey rounds, whereas when the autocorrelation is low, it is better to do relatively more survey rounds and a smaller cross-section. Holding nT fixed, with a single baseline: (i) the optimal value of r holding nT fixed is $= 1/\sqrt{\rho}$; (ii) two follow-up surveys will offer more power than a single follow-up survey for $\rho < 0.5$; (iii) three follow-up surveys will offer more power than one or two follow-up surveys for $\rho < 1/6$.

Proof: Set $m=1$ and $nT=K$ in (11), and then take the derivative with respect to r to show (i). Compare the variances with $r=1, 2$, and 3 , to show (ii) and (iii).

Therefore when the total sample size is fixed at K , power will typically be greater using a baseline and 2 post-treatment surveys with a cross-sectional sample of $K/3$ than a single baseline and follow-up for many types of economic data. But it will be rare in practice for more than two post-treatment surveys to be optimal with a fixed total sample size.

In practice the cost of adding another cross-sectional unit versus surveying the same unit a second time can differ. In many experiments there can be large fixed costs of adding additional units to the experiment. These fixed costs can include the costs of screening and enrolling more subjects in the study, the cost of the intervention itself, and potentially the cost of more handheld units for surveying them. Denote the fixed costs of another cross-sectional unit by a . There can also be fixed costs of conducting another survey round, such as the need to pay field managers for more months of work. Denote the fixed cost of another time round by b . Finally denote the marginal cost of another survey, whether cross-sectional or temporal, by c . Then, assuming only one baseline, with a fixed budget D , one can solve for the optimal number of follow-up rounds

and cross-sectional units by minimizing the ANCOVA variance in (11) subject to $an+br+cn(r+1) = D$.⁶ This does not have a closed form solution, but can easily be solved numerically for specific cases.

3.3. What is the marginal gain to another post-treatment round?

Finally, in many experiments researchers have a fixed cross-sectional sample, often dictated by the pool of eligible applicants for some pilot program they are investigating. The question then facing the researcher is how many survey waves to collect. Consider the difference-in-differences estimator, and the gain in power from collecting $r+1$ rounds compared to r rounds of post-treatment data. This gain in power is proportional to the difference in the variances, and so using (12) we have:

$$\text{Difference-in-difference Gain} = \frac{(1-\rho)}{r(r+1)} \quad (14)$$

Note that the gain in power from adding more post-treatment rounds to difference-in-differences is the same as the gain to adding more post-treatment rounds to post estimation, and thus the gain in (14) is the same as that calculated for post-estimation by Vickers (2003). Using (11), we see that this is also the gain in power from adding more post-treatment rounds to ANCOVA estimation.

Fact 10: There are diminishing marginal returns to adding more post-treatment rounds in terms of the gain in power they give. The greatest gain is from moving from one to two post-treatment rounds, and the gains are smaller the higher is the autocorrelation.

Proof: One can easily determine that the derivatives of (14) with respect to both r and ρ are both negative.

Given the symmetry of the role of pre-treatment and post-treatment surveys in difference-in-difference estimation, we see the same holds for adding more pre-treatment rounds. For ANCOVA estimation, the gain from adding pre-treatment rounds is different from that from adding post-treatment rounds in general, and the gain from moving from one to two pre-treatment rounds is less than that from moving from one to two post-treatment rounds when $\rho < 1$.

3.4 Numerical Illustrations

To illustrate how much the required cross-sectional sample size can be reduced when more survey rounds are undertaken, Table 3 presents the minimum treatment group size n obtained

⁶ This assumes that the treatment and control groups are the same size. When the cost of adding another treatment greatly exceeds that of adding another control, optimal power with a given budget can be achieved by allocating more units to the control group than to the treatment group (See Duflo et al, 2008). Conditional on doing this, it may still be optimal to allocate fewer cross-sectional units to more survey rounds.

under power calculations with different values of r , m , and ρ . I consider a hypothetical experiment intended to detect a 10 percent increase in business profits from a baseline value of 100. Microenterprise profits are noisy, so it is common for the standard deviation to be of the same order of magnitude as the mean. I therefore take the standard deviation as 100, and fix the power at 80 percent and size at 5%. Panel A then shows the treatment group sample sizes required for post estimation, Panel B for difference-in-differences estimation, and Panel C for ANCOVA estimation, for $\rho \in \{0, 0.25, 0.5, 0.7, 0.95\}$. It is assumed that the control group is the same size as the treatment group in these calculations.

Table 3 illustrates numerically Facts 1-6, and Fact 10. Comparing the sample sizes in Panel A and B, we see Facts 1 and 3. When there is only one baseline, difference-in-differences requires larger sample sizes than post analysis when $\rho < 0.5$, the same sample sizes for $\rho = 0.5$, and lower sample sizes for $\rho > 0.5$. The difference in sample size can be large. For example, with a single baseline and follow-up, when $\rho = 0.25$, one would need a treatment group size of 2355 with difference-in-differences, compared to 1570 with post analysis. Adding a second pre-treatment survey reduces the sample size for difference-in-differences to 1766, consistent with Fact 3 (with 2 baselines, difference-in-differences only has more power than post for $\rho > 1/3$). Comparing Panels A and B to Panel C we see consistent with Fact 2 and 4 that ANCOVA requires the same sample size as post when $\rho = 0$, and otherwise requires lower sample sizes than either difference-in-differences or post. Thus in the case of a single baseline and follow-up and $\rho = 0.25$, ANCOVA requires a treatment group size of 1472, compared to the 1570 with POST and 2355 with difference-in-differences. We see in particular that ANCOVA does substantially better than difference-in-differences when ρ is low, and substantially better than POST when ρ is high.

Panel B also illustrates Fact 5. For a fixed number of waves T , the required sample size is smallest when the number of pre-treatment and post-treatment waves are equal. Thus with $T=4$, the treatment sample size required with $\rho = 0.5$ is 785 with 2 pre-treatment waves and 2 follow-ups, compared to 982 with one baseline and three follow-ups. We also see the sample sizes required when $m=1$ and $r=2$ are the same as those with $m=2$ and $r=1$. In contrast, as per Fact 6, we see ANCOVA favors more post-treatment waves than pre-treatment waves when ρ is low. Thus the treatment sample size required with $\rho = 0.5$ is 785 with one baseline and 2 follow-ups, compared to 1047 with two baselines and 1 follow-up.

Finally one can also observe Fact 10, the diminishing gain from adding more survey rounds, in Table 3, with the amount of the gain lower the higher is ρ . Thus for difference-in-differences with one baseline, when $\rho = 0$ the gain from going from one to two post-treatment waves is a reduction in the treatment group size of 785, whereas the gain in going from two to three post-treatment waves is only 261. When $\rho = 0.95$, the gains are only a reduction in treatment size of 39 when going from one to two post-treatment waves, and 13 in going from two to three post-treatment waves.

Table 4 illustrates the differences in power obtained in changing the allocation of a fixed total sample size between n and T . We fix $nT = 1000$, and consider different combinations of cross-sectional and time series samples. Again we assume a mean and standard deviation of 100, and a treatment effect of 10 percent. Panel A illustrates Fact 7, showing that $T=1$ is always best when $\rho > 0$ for POST analysis. Panel B illustrates Fact 8, demonstrating that the power is the same regardless of how n and T are split, so long as $r=m=T/2$. Finally, Panel C illustrates Fact 9, that for a given total sample, sometimes power can be greater when doing a baseline and multiple follow-ups, than by doing a single baseline and single follow-up. For example, when $\rho=0.25$, power is greater doing one baseline and two follow-ups with $n=333$, than doing a single baseline and single follow-up with $n=500$, but also greater than doing one baseline and three follow-ups with $n=250$.

As a final illustration, consider the power to detect an impact of microfinance on business profits. Banerjee et al. (2010) report a mean of 550 and standard deviation of 46604 for business profits. With such noisy data, the treatment and controls group sample sizes required to detect a 10% increase in profits with 90 percent power using a single baseline and follow-up are over 15 million! Suppose then that they were able to consider a more homogeneous set of firms and measure profits more accurately⁷, reducing the standard deviation to 550. Then assuming an autocorrelation of profits of 0.25, with their sample of approximately 1150 treatment and 1150 control, the power for detecting a 10% increase in profits would be 0.669 with a single cross-section post-treatment, 0.697 with a baseline and single follow-up, 0.892 for a baseline and two follow-ups, and 0.952 with a baseline and three follow-ups.⁸ Likewise, taking the example of Karlan and Zinman (2010), who have a control group mean of 17,000, if the standard deviation were the same as the mean, the power to detect a 10% increase in profits would rise from 0.68 with a single post-treatment survey as they have to 0.902 for a baseline and two follow-ups and 0.958 with a baseline and three follow-ups. In both cases then, assuming the standard deviation of profits can be kept or reduced to a reasonable level, the choice of a second or third post-treatment measure would allow them to detect a treatment effect of interest with considerably more power than possible with only a single survey round.

4. Recommendations for Practice and other Practical issues

The above analysis has shown that there are gains to be had from moving beyond the paradigm of single baseline and follow-up. In this section I discuss first some basic guidelines for using these results in practice, and then discuss other practical issues that might affect the choice of how many survey waves to carry out.

⁷ They construct profits as revenue less expenses. De Mel et al. (2009) show that this leads to considerably noisier profit measures than directly asking for a single profits number in their experiments.

⁸ These power calculations ignore intra-cluster correlation for simplicity, and because it is typically low for an outcome like profits.

4.1. Guidelines for practice

1. *Highly autocorrelated outcomes:* For outcome measures like anthropometric measures or test scores, for which the autocorrelation is high (e.g. $\rho=0.6$ to 0.8), always include at least one baseline. Difference-in-differences and ANCOVA have much greater power than POST in these cases. Moreover, Bruhn and McKenzie (2009) also show that the power improvements from stratified or matched randomization are highest when ρ is high. However, if the total sample size is fixed, a single baseline and follow-up will offer more power than multiple pre-treatment or post-treatment rounds when ANCOVA is used. If the treatment and control sizes are fixed, the gains from going from one to two post-treatment surveys can still be non-trivial in these cases, but there is little gain from more than say 3 post-treatment surveys.

2. *Outcomes with low autocorrelation:* For outcome measures like business profits, incomes, or expenditure, for which the autocorrelation is typically low (e.g. $\rho=0.20$ to 0.40), it can be optimal to have no baseline at all, and just do a single follow-up survey if the total sample size is limited. If the treatment group size is fixed, researchers can dramatically increase power by doing multiple post-treatment surveys. Even if a baseline is taken, researchers should not use difference-in-differences in such cases, since doing so has much lower power than either POST or ANCOVA analysis.

4.2 Other Practical issues

In practice there are several other factors that should guide researchers in choosing how many survey rounds to conduct. I note some of the key factors here, and their implications for choice of the number of pre-treatment and post-treatment waves:

1. *Over what horizon is a pooled treatment effect relevant and of interest?* The analysis in this paper has assumed a common treatment effect γ . Of course if the treatment effects vary over individuals, researchers are usually content to estimate an average treatment effect, and the analysis here will still hold. However, in some experiments the effect of the treatment may also vary over time. In this case estimation of γ by pooling multiple post-treatment survey waves will yield an average treatment, where the average is over multiple waves. If the survey waves are relatively close together in time (e.g. monthly or quarterly), then combining several post-treatment waves and getting the average treatment effect over a period 9-15 months post-treatment is likely to be reasonable.⁹ In contrast, if there is reason to believe the effects differ dramatically with time since treatment, one will not want to average over long periods. High seasonality may provide another reason to conduct multiple measures – it may be of more interest to get the

⁹ Researchers interested in time since treatment effects can then combine multiple measures around 1 year, around 2 years, etc. See De Mel et al. (2008) for an example, in which quarterly waves are combined to look at how treatment effects vary over the first year since treatment, second year since treatment, etc.

average impact over high and low demand periods than to get the impact only at one particular point in time.

2. *Survey compliance and attrition:* Conducting multiple survey waves increases the burden on respondents, which might increase attrition. Using multiple pre-treatment waves can be beneficial in this respect, by eliminating the individuals most likely to attrit before the randomization is done, one can improve internal validity by randomizing only over individuals that are likely to be found in a follow-up survey. In contrast, if multiple rounds of post-treatment surveys cause significant attrition, this will limit the extent to which researchers will wish to conduct many rounds of the survey. If the survey is just collecting measurement of a few key outcomes, these additional rounds of post-treatment surveys can be short and less burdensome for respondents, which can minimize this drop-out. Secondly, by conducting multiple post-treatment rounds, researchers stand a better chance of capturing at least once post-treatment individuals who are harder to track down. For example, a business owner who travels temporarily to other towns might get missed in a one-off survey, but may get found when going back at monthly or quarterly intervals. Finally, there is also the possibility that waiting for a long time to re-contact people may make it harder to find them, and make respondents think you have lost interest in them, whereas regular follow-ups may instead these risks.
3. *Will multiple measures change people's reporting or people's behaviors?* Experience with measuring microenterprise profits suggests that respondents may report more accurately after one or two rounds of surveys, perhaps as they better understand the concepts being asked and can recall them better when asked for a second or third time (Samphantharak and Townsend, 2009; Fafchamps et al, 2010a). This suggests a benefit to researchers of conducting more than one pre-treatment survey. However, in some circumstances there will be a concern that asking the same question multiple times will either change the way people respond, or their behavior. For example, Zwane et al. (2010) summarize the results of five experiments in which the frequency of surveying was varied. They find being surveyed more frequently lowers reported child diarrhea rates and leads to more use water treatment products and take-up of medical insurance. However, they find no effect of being surveyed on borrowing behavior. The risk is therefore that in some settings and for some outcomes, repeated surveying may serve as reminders to increase the salience of neglected actions. Finally, repeatedly asking individuals the same questions may change reporting due to fatigue. For example, individuals who are repeatedly asked about expenditure may quickly learn that they can reduce the length of the questionnaire by saying "no" to questions which when answered positively lead to lengthy detailed questions about what was spent.
4. *Cost considerations:* Surveying a smaller cross-section over multiple survey waves can result in a different cost than doing a larger cross-section single baseline and follow-up. Whether the cost is higher or lower will depend on country context. On one hand, a smaller cross-sectional sample with more survey waves allows a smaller survey team to

be used for longer periods of time, potentially resulting in higher average quality enumerators. In addition, it can lower the costs of listing since a smaller cross-sectional sample is used. Of greatest cost savings in many experiments is that it also avoids the costs of paying for the intervention for as many units. On the other hand, the team is in the field for a longer period of time, which can raise costs.

5. *Learning by doing.* Even in cases where researchers have some power to detect a treatment effect with one post-treatment survey round, it can be useful to plan multiple survey rounds relatively close together in time. This allows researchers to quickly analyze the early results from the first follow-up survey, and based on these, ask follow-up questions in the next post-treatment survey to explore new hypotheses generated by the results.
6. *How do we know what ρ is?* Power calculations already require substantial insights from researchers in terms of what the likely mean, standard deviation, and treatment effect size of interest are. Pilot surveys or existing data are often used to give some sense of likely parameters. In most cases researchers will not have data on the autocorrelation of the outcome of interest. It is hoped that the data provided in this paper for different outcomes from different surveys will therefore provide a starting point for researchers, and that more researchers will report these autocorrelations in future experiments.
7. *Can we just obtain multiple measures more cheaply by recall?* A cheaper alternative to conducting multiple post-treatment or pre-treatment rounds is to ask multiple measurements in a single survey, with recall. While intuitively appealing, the value of this approach is likely to be limited in practice, since it is precisely the types of variables that are noisiest and hardest to measure in practice for which the data are typically less autocorrelated and for which multiple measures are of most value. For small informal firm owners who do not keep books, asking profits with recall over multiple months is difficult, while asking expenditure month by month or quarter by quarter with recall is likely to be highly inaccurate. Gibson and Kim (2010) show even with wage workers in the United States that retrospective recall is problematic, with workers underreporting transitory variation in earnings, creating non-classical measurement errors. However, such a strategy could be used in cases where good records are available, such as in experiments with larger firms which have accurate books or records.¹⁰
8. *To baseline or not?* The power calculations above suggest that, in a number of cases, it can be optimal in terms of power to conduct a single post-treatment survey of size $n=K$ than to do a baseline and follow-up with $n=K/2$. However, there are several other factors to consider in choosing whether or not to use a baseline. A baseline can be used to stratify the randomization on key variables, improving power and providing a basis for examination of treatment effect heterogeneity. It is often used to examine what determines take-up of some intervention. It can be useful for verification of

¹⁰ See e.g. Bloom et al. (2010) who collect daily and weekly production data from plants with over 100 workers each once a month.

randomization in cases where there is a risk of the randomization not being implemented perfectly, and can also be used to test whether attrition is non-random in terms of baseline characteristics. Finally a baseline, and especially multiple pre-treatment surveys, offer the possibility of matched difference-in-differences as a back-up evaluation strategy in cases where there is a risk that the randomization may not get implemented in practice or a risk that take-up of a program may be lower than anticipated.

However, when the outcome has low autocorrelation, the baseline does not reveal very much about likely future outcomes, and thus can be an expensive undertaking. Researchers attempting to implement large-scale evaluations with Governments or NGOs, where there is reasonable uncertainty as to whether randomization will actually be carried out and whether they will have sufficient take-up. For example, consider a micro-savings intervention, where a Government or NGO agree to randomly choose villages in which to introduce a new savings product. There is a risk that after doing baseline surveys in the treatment and control villages that the Government changes its mind, and decides to introduce the product in all villages. There is also a risk that no one uses the new product, in which case there is no possibility of measuring the impact of savings accounts on household outcomes. In such a case, practical considerations may suggest it is optimal to not carry out a baseline, and then wait and only carry out post-treatment surveys if the product is indeed randomly introduced and take-up is high.

5. Conclusions

This paper has shown that when the autocorrelation in outcome data is low, as is common with outcomes of interest like business profits, expenditure, and income, the standard paradigm of single baseline and follow-up, followed by difference-in-differences analysis, is unlikely to be optimal. Large improvements in power can be obtained from multiple post-treatment measures in experiments with fixed treatment and control group sizes, and from using ANCOVA instead of difference-in-differences. Researchers choosing how to allocate a fixed budget over multiple surveys may find they can obtain more power by not conducting a baseline at all, and if they use a baseline, will often get more power doing two follow-up waves with a smaller cross-sectional sample size than a single follow-up with a larger cross-sectional sample.

These findings are particularly likely to be of interest and use to researchers conducting experiments with interventions to help the poor, since the profits, incomes, and expenditures of the poor are typically more volatile and less autocorrelated than those of stable wage earners for example. In many cases the size of the treatment group is determined by the number of units eligible for some pilot initiative, and so hopefully researchers can extract much more out of these samples by considering multiple measurement.

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Table 1: How stable is the autocorrelation over time?

	Ghana					Sri Lanka		
	Microenterprise		Log Profits Control	Household	Log Household	Microenterprise		
	Profits Control	Profits Treatment		Expenditure Control	Expenditure Control	Profits Control	Profits Treatment	Log Profits Control
Correlation between t=1 and:								
t=2	0.148	0.334	0.438	0.188	0.376	0.413	0.464	0.521
t=3	0.451	0.440	0.469	0.292	0.365	0.375	0.390	0.516
t=4	0.382	0.462	0.438	0.249	0.334	0.387	0.357	0.501
t=5	0.323	0.504	0.442	0.189	0.340	0.393	0.242	0.521
t=6	0.313	0.578	0.390	0.240	0.351	0.282	0.324	0.468
Correlation between t=2 and:								
t=3	0.372	0.706	0.695	0.316	0.465	0.433	0.649	0.664
t=4	0.219	0.409	0.607	0.229	0.353	0.563	0.497	0.653
t=5	0.207	0.584	0.538	0.278	0.412	0.545	0.449	0.645
t=6	0.318	0.398	0.523	0.191	0.411	0.413	0.493	0.577
Average autocorrelation	0.303	0.490	0.504	0.241	0.378	0.423	0.430	0.563
Average N:	325	344	307	384	360	220	318	220

Notes:

Time periods correspond to calendar quarters.

Table 2: Examples of Autocorrelations for Other Economic Outcomes

Outcome	Source	Country	Time Interval	ρ
Household Income	Gibson and McKenzie (2010)	Tonga	6 months	0.38-0.47
		Vanuatu	6 months	0.19-0.21
Household Expenditure	Gibson and McKenzie (2010)	Tonga	6 months	0.12-0.33
		Vanuatu	6 months	0.35-0.53
	Boozer et al. (2010)	Ghana	6 months	0.32 (single-report)
	Gibson et al. (2003)	Urban China	2, 4 and 6 months	0.58-0.66 (separate reports)
Individual Labor Income	EPH May and October 2002 (see McKenzie, 2004)	Argentina	6 months	Below median income: 0.25 Above median income: 0.79
		Mexico	3 months	Below median income: 0.29-0.31 Above median income: 0.50-0.53
	ENE 2003:1-2004:1 (see Bruhn, 2010)		6 months	Below median income: 0.22-0.31 Above median income: 0.49
Math test scores	Das et al. (2007)	Zambia	1 year	0.68
	Andrabi et al. (2010)	Pakistan	1 year	0.61
	Banerjee et al. (2007)	India	2 years	0.59
Language test scores	Das et al. (2007)	Zambia	1 year	0.68
	Andrabi et al. (2010)	Pakistan	1 year	0.65-0.66
	Banerjee et al. (2007)	India	2 years	0.51

Table 3: How does the cross-sectional sample size required vary with correlation and rounds

Panel A: Sample Sizes required with Post Estimation

Pre	Post	p=0	p=0.25	p=0.5	p=0.7	p=0.95
0	1	1570	1570	1570	1570	1570
0	3	524	785	1047	1256	1518
0	5	314	628	942	1194	1507
1	1	1570	1570	1570	1570	1570
1	2	785	982	1178	1335	1531
1	3	524	785	1047	1256	1518
1	4	393	687	982	1217	1511
2	1	1570	1570	1570	1570	1570
2	2	785	982	1178	1335	1531
2	3	524	785	1047	1256	1518
3	2	785	982	1178	1335	1531
4	1	1570	1570	1570	1570	1570

Panel B: Sample Sizes required with Difference-in-Differences

Pre	Post	p=0	p=0.25	p=0.5	p=0.7	p=0.95
1	1	3140	2355	1570	942	157
1	2	2355	1766	1178	707	118
1	3	2094	1570	1047	628	105
1	4	1963	1472	982	589	99
2	1	2355	1766	1178	707	118
2	2	1570	1178	785	471	79
2	3	1309	982	655	393	66
3	2	1309	982	655	393	66
4	1	1963	1472	982	589	99

Panel C: Sample Sizes required with ANCOVA

Pre	Post	p=0	p=0.25	p=0.5	p=0.7	p=0.95
1	1	1570	1472	1178	801	154
1	2	785	883	785	566	114
1	3	524	687	655	487	101
1	4	393	589	589	448	95
2	1	1570	1413	1047	665	117
2	2	785	825	655	430	78
2	3	524	628	524	351	65
3	2	785	785	589	373	65
4	1	1570	1346	942	578	98

Notes: Power calculations calculated for hypothetical experiment with Control mean and standard deviation of 100, treatment effect size of 10%, size 0.05 and power 0.80. ANCOVA with p=0 is the same as POST estimation.

Table 4: How does power vary with n and T holding nT fixed?

Cross-sectional Sample n	Number of Pre-treatment rounds (m)	Number of post-treatment rounds (r)	p=0	p=0.25	p=0.50	p=0.75	p=0.90
Panel A: Post							
1000	0	1	0.609	0.609	0.609	0.609	0.609
500	0	2	0.609	0.516	0.447	0.394	0.368
250	0	4	0.609	0.394	0.293	0.237	0.213
Panel B: Difference-in-Differences							
500	1	1	0.201	0.252	0.353	0.609	0.942
250	2	2	0.201	0.252	0.353	0.609	0.942
250	1	3	0.162	0.201	0.278	0.491	0.865
100	5	5	0.201	0.252	0.353	0.609	0.942
Panel C: Ancova							
500	1	1	0.353	0.372	0.447	0.667	0.952
333	1	2	0.446	0.405	0.446	0.636	0.932
250	2	2	0.353	0.339	0.410	0.641	0.948
250	1	3	0.491	0.394	0.410	0.575	0.889
100	5	5	0.353	0.299	0.379	0.622	0.945
100	1	9	0.564	0.274	0.249	0.332	0.604

Note: Power calculations calculated for hypothetical experiment with control mean and standard deviation of 100, treatment effect size 10%, and size 0.05.