Scrutinizing Alternative Aggregate Frisch Elasticity Estimates With Evidence from the U.S. Budget Sequestration "Experiment"*

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Abstract

The aggregate Frisch elasticity is critical for the evaluation of the outcomes of alternative fiscal and monetary policies as well as of competing interpretations of the business cycle phenomena, but consensus about its magnitude remains elusive. The temporary government spending cuts initiated by a 2013 U.S. budget sequestration procedure had experiment-like features almost ideal for measuring that elasticity from the response of key macroeconomic variables to that policy development. This paper scrutinizes those responses with a Business Cycle Accounting "event study" approach that combines the quantitative methodologies of the estimation and calibration traditions. Its main finding is that single-agent representative models meant to study macroeconomic phenomena that calibrate the aggregate Frisch elasticity to the budget sequestration evidence should favor values for that elasticity in the low end of the range of those that have been proposed as empirically plausible in the literature.

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1 Introduction

Households' willingness to substitute hours worked across periods in response to temporary variations in real wages–the aggregate intertemporal real wage labor supply elasticity–plays a prominent role in the response of aggregate economic variables to a variety of shocks. That elasticity needs to be rather large to validate the hypothesis that total factor productivity shocks are the major source of economic fluctuations at business cycle frequencies in stochastic versions of the Solow growth model with endogenous labor supply considered by Kydland and Prescott (1982). The magnitude of that elasticity is also relevant for policy-related issues, such as the assessment of the fraction of tax cuts self-financed through endogenous labor supply feedback effects.

Given its importance for validating or dismissing alternative interpretations of the business cycle, it is perhaps not surprising that the value of the intertemporal substitution elasticity of hours worked has been the subject of great controversy ever since Lucas and Rapping (1969) inferred it from macroeconomic variables to be 1.4, three times larger than that estimated by microeconomic studies. The debate was originally sparked by the fact that the parameter capturing the aggregate labor supply elasticity in Lucas and Rapping resembled, as seen with particular clarity in MaCurdy (1985), that with which those microeconomic studies typically estimate the so-called Frisch elasticity, that is, the *marginal-utility-of-wealth-held-constant* real wage elasticity of hours worked by already employed individuals. It didn't take the profession long to realize, however, that the resemblance was misleading, because the Frisch elasticity parameter typically estimated by the microeconomic literature measures the real wage elasticity of hours worked along the intensive margin of the labor decision, while the one estimated by Lucas and Rapping included the extensive margin of that choice as well.

The contentious issue of the theoretical underpinnings of Lucas and Rapping's pragmatic approach to measuring the aggregate labor supply elasticity with a single parameter, inclusive of both the *intensive* and *extensive* margins, was tackled by Rogerson (1984, 1988) and Hansen (1985). A key implication of those authors' aggregation theory is that all macroeconomic models hoping to understand the nature of the business cycle need to do in order to accommodate the omission of the latter margin in their analysis is to adjust upward the value of that single Frisch elasticity parameter, relative to the estimates obtained in microeconomic studies.

Despite objections to the empirical relevance of the required assumptions, the simplicity and tractability of the Hansen-Rogerson single parameter device to capture both margins of the labor supply quickly gained traction in the profession, as proven by the large proportion of dynamic stochastic general equilibrium models that appeal to it to gauge, with different methodologies, the aggregate intertemporal substitution elasticity of labor.

The present paper deliberately sticks to that tradition to step into the debate prompted by the empirical issue that the Hansen-Rogerson aggregation theory failed to resolve: by how much should one increase the low values of the Frisch elasticity typically obtained by microeconomic studies in macroeconomic models whose implications depend critically on the size of that adjustment. The paper sets out to revisit this issue, informed by the arguments and counterarguments offered in the heated exchanges prompted by it and by the evidence associated with an unusual fiscal policy development, the temporary non-negligible cuts in government discretionary expenditures prescribed by U.S. legislation that triggered a budget sequestration administrative procedure in 2013.

The reason to focus on that fiscal policy regime change, referred to hereafter as "budget sequestration," is that, based on arguments offered later, it had the same "natural experiment" features of the fiscal policy developments that led Prescott (2004) and Chetty, Guren, Manoli, and Weber (2013) to conclude that the Frischian labor supply elasticity is high, in the order of 3.0, or rather low, in the order of 0.75, respectively.

Interestingly enough, the discrepancy cannot be attributed entirely to methodological differences, because both papers inferred the Frisch elasticity value by respecting the "calibration approach" rules of the game. The guiding principle behind the calibration approach has been forcefully stated by Prescott (1986): "*parameters cannot be specific to the phenomena being studied.*" According to this view, parameter values that pay a crucial role in the answer to a macroeconomic question must be independently validated by their ability to account for an unrelated phenomenon. Later on in the same paper Prescott hinted at the possibility that such independent verification could be achieved by exploiting fiscal policy differences across countries and/or time.

Paying heed to his own advice, Prescott (2004) proceeded nearly thirty years later to calibrate the value of the parameters controlling the aggregate intertemporal elasticity of labor substitution to that which, under certain assumptions, accounted for the differences in the households' allocation of time to work in countries with different labor income tax rates. Prescott's (2004) inferred value of 3.0 for the aggregate Frisch elasticity happened to be as high as needed to render innovations to total factor productivity the major source of economic fluctuations in versions of the model economy he studied with Kydland in their cited 1982 paper.

Following Prescott's lead, Chetty *et al.* (2013) applied the same calibration approach to infer the magnitude of the aggregate labor supply elasticity from fiscal policy developments with "natural experiment" features implemented in Iceland in 1987, and in Canada in the 1990s. They computed the labor supply responses predicted by the macroeconomic model developed by Rogerson and Wallenius (2009) to the tax and subsidy changes that those countries introduced for a limited period of time. From the comparison of simulated outcomes to actual ones, Chetty *et al.* (2011) recommended "*to calibrate representative agent macro models to match a Frisch elasticity of aggregate hours of 0.75.*" This modest aggregate Frisch elasticity value significantly reduces the ability of total factor productivity shocks to account for business cycles implied by Prescott's much higher calibrated value.

In the light of those contradictory findings, this paper couldn't resist the temptation of scrutinizing, with a methodology in the spirit of the calibration approach, which one of several aggregate Frisch elasticity values proposed in the literature is most favored by the evidence associated with the budget sequestration "experiment" that came into effect in 2013. It does so, however, with a metric, the value of the likelihood function implied by different Frisch elasticity values, that takes into account criticism of the "estimation" school of thought that argues that, despite its independent verification appeal, the calibration approach doesn't make use of the statistical metrics, typically imparted by the proposed stochastic model economy, to establish the extent to which the evidence favors certain values of unknown parameters over others.

Before providing an overview on how the paper blends those two alternative quantitative methodologies into one suitable for accomplishing its goal, it is important to provide a rationale for the model economy adopted as a measuring device.

The model selection was partially inspired by the observation in Ljungqvist and Sargent (2011) that the high Frisch elasticity value inferred by Prescott can be traced in large part to the omission of government supplied non-employment benefits from the analysis. Once included, a Frisch elasticity of 3.0 predicts that hours worked will be much larger than observed in the European countries he examined. The key message that Ljungqvist and Sargent extract from this counterfactual prediction is that the large intertemporal elasticity of labor substitution eventually built into a model may be disarmed by institutional features of the environment, taxes, nonemployment subsidies and, more generally, government policies that alter the fraction of individuals indifferent about working and not working.

This paper takes that observation as a proposal for a research agenda guided by the principle that attempts to measure the aggregate Frisch elasticity must be conducted with models simultaneously capable of gauging the frictions in labor and capital markets present in the actual economies under study. For that reason, this paper constructed the model economy along the lines of the Business Cycle Accounting (BCA) approach pioneered by Chari, Kehoe, and McGrattan (2007)—(CKM). This approach is particularly well suited to the task, because it introduces into the frictionless neoclassical growth model auxiliary variables ("wedges") that stand in for a variety of distortions potentially important for the correct interpretation of business cycles and other phenomena.

An additional attribute of the BCA approach is that when the economic agents' optimal decision rules are approximated with standard first order perturbation techniques, it renders itself easily to a state-space representation of the model economy that almost naturally invites one to combine elements of both the "estimation" and "calibration" traditions with a methodology particularly instrumental for the goal of this paper. The organizing principle behind that methodology is that different Frisch elasticity values, along with a consistent set of parameters estimated as indicated later, are more likely than others to have induced in macroeconomic aggregates the dynamics observed during the budget sequestration period.

The methodology developed by the paper involves two stages. Both of them will appeal to standard first order perturbation techniques to approximate the economic agents' optimal decision rules around the non-stochastic steady state of the economy. The second stage, however, will take into account that those rules will not be invariant to the policy regime change represented by the budget sequestration spending cuts.

Of course, the decision rules depend on unknown states and parameter values that need to be somehow estimated. It is important to emphasize at this point, however, that the Frisch elasticity will not be included in the set of parameters to be estimated, given that the goal of the paper is to check which of the existing estimates more commonly invoked as empirically relevant in the literature account best for the performance of macroeconomic variables induced by the budget sequestration. To that effect, the paper will implement both stages of the methodology for each of five of such existing Frisch elasticity estimates, in the range of 0.5 to 3.0, selected with the arguments provided in section 4.4.

The first stage of the methodology proceeds to estimate, for each selected Frisch elasticity value, the unknown state variables and parameters of the model economy with a rather standard maximum likelihood implementation of the Kalman filter. Such implementation is made quite straightforward by the state-space representation of the model economy induced by the approximation of the decision rules as indicated above, as well as by appropriate assumptions about the stochastic processes governing the evolution of the wedges and other exogenous variables. Mindful of the calibration principle, the estimation is performed with available data only up to 2012, excluding observations after 2013 when macroeconomic variables started to register the effects of the budget sequestration, according to evidence discussed in section 2.

The outcome of this first stage of the methodology are five sets of estimates of unknown states and parameters that are statistically consistent with each of the corresponding values assumed for the Frisch elasticity. Given that the debate about the value of that elasticity has been largely prompted by its implications for the adjudication of the economic fluctuations at business cycle frequencies to different sources, the paper proceeded to calculate the standard business cycle statistics induced by each of those combinations of parameter estimates.

It turns out that, according to the "method of simulated moments" metric often used in the literature, the combination of parameter estimates indexed by the highest value of the Frisch elasticity considered, 3.0, is the one which maximizes the fraction of the business cycle accounted for by total factor productivity shocks. From the perspective of the calibration principle, however, setting the aggregate Frisch elasticity parameter to that high value just because it is the most favorable to total factor productivity shocks as a source of the business cycle amounts to a tautology, unless independently validated with an unrelated phenomenon.[1]

This is where the paper could not let pass the opportunity to apply the calibration

[1] It is for that reason that Prescott (1986) refused to accept the much higher aggregate Frisch elasticity value of 5.0 estimated by Eichenbaum, Hansen, and Singleton (1984).

principle to the budget sequestration spending cuts that became effective in the U.S. in 2013. As described, the paper takes the stand that the trigger of those cuts took economic agents by surprise, justifying with arguments similar to those offered by Chetty *et al.* (2013) the calibration of the value of the aggregate Frisch elasticity to that which accounts best, among those considered, for the performance of macroeconomic aggregates during the budget sequestration period. This paper imposes the requirement that the criterion by which that is established should not ignore the statistical metrics implied by the model, as vigorously demanded by the estimation school of thought. That requirement is accomplished in the second stage of the methodology by ranking the ability of the different Frisch elasticity values considered and their associated estimated state variables and parameters from the first stage, by the value of the likelihood of the observable variables in the years for which the budget sequestration was in place, after appropriately taking into account the new economic agents' optimal decision rules induced by the policy regime change.

According to the resulting ranking, the responses of macroeconomic aggregates to a fiscal policy development mimicking the conditions of a natural experiment, measured with a methodology that incorporates the estimation and calibration empirical perspectives, better favors the low than the high aggregate labor supply elasticity value that Chetty *et al.* (2011) and Prescott (2004), respectively, calibrated as well to fiscal policy related evidence. This finding is certainly consistent with the low to moderate magnitude of that elasticity that various studies have inferred or estimated from microeconomic data or from aggregate variables, such as those by Heathcote, Storesletten, and Violante (2010, 2014), Fiorito and Zanella (2012), and Ríos-Rull, Schorfheide, Fuentes-Albero, Kryshko, and Santaeulàlia-Llopis (2012).

The rest of the paper is organized as follows. Section 2 goes over some background material and chronology of events regarding the fiscal policy regime change prescribing the cuts in U.S. government spending that motivated the question the paper seeks to answer.

Section 3 discusses the main ingredients of the model economy, as well as the measurement and specification issues that had to be addressed to improve the accuracy of the inferences about the value of the aggregate Frisch elasticity obtained by the paper. Section 4 rigorously lays out the model economy. Section 5 presents an overview of the quantitative methodology proposed by the paper, goes over the details of implementation of the estimation stage of that methodology, discusses the business cycle implications of the different sets of parameter estimates obtained in that stage, and explains how the subsequent calibration stage scrutinizes which of those combination of parameter estimates, indexed by a corresponding existing estimate of the aggregate Frisch elasticity, is more consistent with the responses of observable macroeconomic variables during the budget sequestration period. Section 6 reports the findings. Section 7 offers concluding remarks.

2 The Budget Sequestration Spending Cuts

2.1 Relevant Chronology and Details

In the U.S., the government can borrow to finance any shortfall of revenues relative to expenditures up to a certain "debt ceiling" set by Congress. The authorization step is usually a formality, as it simply provides the U.S. Treasury the means to pay for government spending previously agreed upon. That was not the case, however, in January 2011, when the U.S. Treasury request for a debt ceiling increase was opposed by lawmakers concerned with the explosive debt scenario that the Congressional Budget Office (CBO hereafter) had projected in a June 2010 report. These legislators demanded that any increase in the debt ceiling should be accompanied with fiscal deficit reduction measures that prevented the materialization of that debt scenario. There was, however, much disagreement over the specific measures and the prolonged negotiations brought the U.S. to the brink of a sovereign debt default. A last minute deal, the Budget Control Act signed into law on August 2, 2011, avoided that outcome but included two unusual provisions intended to prevent the government debt from exploding.

One created a bipartisan Joint Select Committee on Deficit Reduction in charge of prescribing measures to reduce fiscal deficits in a cumulative amount of \$1.5 trillion (about 10% of GDP at the time) over fiscal years 2012-2021. The other unconventional provision was a contingent clause stipulating that if the Joint Committee failed to propose, or Congress failed subsequently to enact, legislation to cut the deficit by at least \$1.2 trillion by January 15, 2012, existing caps on budget authority to spend would be reduced in that cumulative amount, including savings in servicing the government debt, starting in January 2013 and continuing through fiscal year 2021. In practice, this contingent clause meant that the fiscal stabilization that the Budget Control Act sought to ensure would be delivered either by the deliberate measures eventually proposed by the Joint Select Committee or by automatic spending cuts evenly split between discretionary defense and non-defense programs.

From an operational point of view, the budget sequestration procedure prescribed in the legislation was necessary to revoke or "sequester" previously authorized expenditures above the new spending caps. This is the reason why all the spending cuts eventually triggered by the contingent clause will be generically referred to throughout the paper as budget sequestration spending cuts, even if not all of them applied to already authorized expenditures.

An important detail for building a model economy that adequately captures critical features of the actual one under study is that it was understood that the sizable federal government outlays on civil and military payrolls would be largely excluded from budget sequestration. The measure wasn't projected, therefore, to notably affect public sector employment. In addition, the Budget Control Act also shielded most mandatory programs from the sequester. These two exclusions made it possible to treat output in the model economy as produced exclusively by the privately owned firms and address therefore, with the procedure proposed by Gomme and Rupert (2007), measurement inaccuracies with the potential to distort the inferences about the value of the aggregate Frisch elasticity obtained with the "event study" approach adopted in this paper. As will become clearer later, the only effect of variations of government spending in the modified "private sector only" economy is to increase or decrease the public sector absorption of private sector output.

According to the Congressional Budget Office (2012), if implemented, the budget sequestration spending cuts would lower that absorption as a share of GDP to the lowest levels on record.[2] Despite the incentives to avert this, in principle, unpalatable extreme spending austerity, the Joint Committee announced on November 2011 that, *"after months of hard work and intense deliberations",* it had concluded that it wouldn't be possible to reach an agreement on an alternative fiscal deficit reduction package before the January 15, 2012 deadline specified in the Budget Control Act.

Still, the fact that the cuts would reduce discretionary spending as a share of GDP to levels not seen before, eventually impairing the ability of government agencies to adequately perform core functions, kept alive throughout all of 2012 the hopes that Congress would eventually act to avoid them. Such hopes weren't misplaced, given that lawmakers were considering whether or not to extend tax cuts enacted in 2001 and 2003 due to expire precisely that year. It was plausible to speculate that the negotiations inevitably required to change the tax code would offer legislators a golden opportunity to come up with alternative deficit reduction measures that met the conditions to cancel, or at least suspend, the budget sequestration. Such speculation may have been reinforced by repeated public statements from Congress and even the President insisting on their determination to find a compromise.[3]

It is reasonable to conjecture, then, that at the end of 2012 economic agents were highly

[2] More specifically, in table 1-1 of the cited CBO report, discretionary spending at the end of the sequestration period, in 2021, was projected to represent 5.7 of GDP, the lowest level since at least 1972.

[3] According to press reports, the Department of Defense, one of the federal agencies that would be hit particularly hard by the spending cuts, wasn't making any contingent plans to deal with them as late as September 2012.

skeptical that the unusually large and long-lasting budget sequestration spending cuts would be ever implemented. The paper also takes the stand that that perception changed when the Taxpayer Relief Act enacted in the dawn of 2013 extended some expiring tax cuts, but failed to take any substantial action with respect to the spending cuts, other than postponing their implementation from the originally slated date, January 2, 2013, to March 1, 2013. These assumptions are not mere speculation, as their empirical plausibility was investigated and established by Hu and Zarazaga (2018) with a version of the model economy that differs from the one in the present paper in some specification and implementation details.

2.2 Estimated Size of the Budget Sequestration Spending Cuts

As could be expected, the inferences about the value of the Frisch elasticity obtained by examining the performance of macroeconomic variables under the influence of the budget sequestration spending cuts will depend on the magnitude and distribution over time of those cuts in *real terms*. That information is not readily available, because government budgets are typically approved in nominal terms. Even then, the transformation of nominal spending cuts into real ones requires one to make assumptions about the evolution of the inflation rate over the budget sequestration period. In addition, it is necessary to make assumptions about the growth rate of private sector output, because in the model economy the spending cuts will be introduced as a policy regime change that shifts downwards, for its duration, the stochastic process otherwise governing the evolution of the ratio of the government absorption of goods and services to that output.

In any case, the calculation of the statutory spending cuts implied by the budget sequestration in real terms must start from a reliable sequence of nominal ones, fortunately made available by the Congressional Budget Office (2013), as summarized in the second column of Table 1.

Given that the Budget Control Act was motivated by the desire to stabilize the government debt-output ratio, it seems reasonable to assume that the size of the nominal spending cuts was determined by the target of reducing fiscal deficits by an amount equivalent to a certain percentage of output. It follows that that legislation must have taken into account that the ability of those cuts to achieve that target would be ultimately determined by the projected growth of nominal output.

Table 1: Annual government spending cuts implied by the Budget Control Act

Year	**$ billion** (*)	**% of private sector output (**)**
2013	35	0.24
2014	75	0.50
2015	85	0.54
2016	89	0.55
2017	90	0.54
2018	90	0.52
2019	89	0.49
2020	88	0.47
2021	87	0.45
Sources: (*) CBO (2013), p. 10 and Table 1-5, p. 27. (**) Authors' calculations.		

It made sense therefore to conjecture that, in mandating the nominal government spending cuts documented above, U.S. lawmakers counted on the Federal Reserve to keep the inflation rate close to the 2% annual target.[4] The calibration of the model economy, presented later, suggests that it was realistic at the time to also project annual real output growth rates of around 1.5%. The two rates combined imply a 3.5% annual growth rate of nominal output over the budget sequestration period.

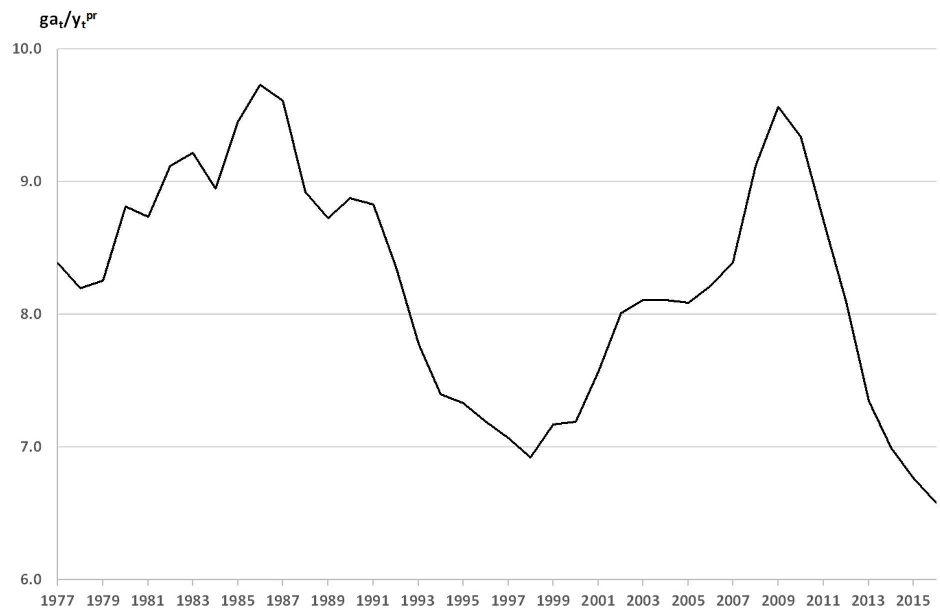
Accordingly, the spending cuts in real terms per unit of output implicitly targeted by the Budget Control Act, presented in the last column of Table 1, were "reverse engineered"

[4]This assumption is consistent with the projections of several inflation rate indicators adopted by the CBO, as reported in Table B-1, p. 64, of the same publication cited as the source of the data for Table 1.

with the standard procedure of dividing their explicitly stipulated nominal counterparts by the private sector nominal GDP in 2012 and subsequently deflating the resulting figures by the projected nominal growth rate of output inferred above.[5]

It is worthwhile pointing out that according to available data as of the time of this writing shown in Figure 1, the government absorption of private sector output declined to historically low levels while the provisions of that legislation were in place, favoring the interpretation of the paper that the spending cuts prescribed by it constituted a policy regime change, rather than a manifestation of the regular ebbs and flows previously displayed over time by that variable.

Figure 1
Government absorption as percent of private sector output



The Budget Control Act did not stipulate spending caps past the year 2021, so it didn't impose any legal restrictions on the level of government absorption of goods and services as a share of private sector output in the long run. This long run value is needed, however, to inform the computation of the steady state equilibrium of the model economy and, therefore,

[5]Nominal private sector GDP in 2012 was $14,126 billion, as estimated from the NIPA prepared with the comprehensive methodological revision introduced in 2013.

of the decision rules ultimately determining the response of macroeconomic aggregates to the government spending cuts under consideration.

The narrative of the previous section, however, lends support to the hypothesis that economic agents perceived the budget sequestration as a fiscal stabilization measure of last resort and, as such, not intended to persist beyond the period explicitly established in the legislation. Accordingly, the paper assumes that at the end of the budget sequestration period, the government absorption of goods and services as a share of private sector output returns to its historical average, as measured in section 4.4 of the paper.

The empirical plausibility of that assumption was subsequently validated by the Tax Cuts and Job Acts of 2018, which cancelled altogether the discretionary spending cuts for the remaining years stipulated in the Budget Control Act. In fact, the temporary nature of the cuts had been implicitly revealed by previous legislation, the Bipartisan Budget Act passed at the very end of 2013, and the Bipartisan Budget Act of 2015, which reduced the size of the spending cuts, relative to those documented in Table 1.

Of course, the modification to the original spending cuts just mentioned had to be taken into account in the quantitative methodology proposed by the paper. For that reason, the updated sequence of future spending cuts in real terms implied by the legislation just mentioned as of the beginning of each year between 2013 and 2016 are documented in Table 2. Notice that the second column of the table simply reproduces the figures in the last column of Table 1. A procedure entirely analogous to that used for that table was followed to estimate the figures in the remaining columns of Table 2 from the nominal spending cuts stipulated by the relevant legislation, as reported in CBO (2014) and CBO (2016).

The fact that the spending cuts originally prescribed by the 2013 Budget Control Act were first reduced in size and then terminated by subsequent legislation raises the issue of the extent to which economic agents believed that those cuts would be implemented, in size and duration, as scheduled at the beginning of each year of the period 2013-2016 for which

Table 2: Discretionary spending cuts as percent of private sector output

Year	Prescribed as of beginning of year				Actually implemented
	2013	2014	2015	2016	
2013	0.24				0.24
2014	0.50	0.25			0.25
2015	0.54	0.43	0.42		0.42
2016	0.55	0.55	0.54	0.24	0.24
2017	0.54	0.54	0.53	0.35	0.35
2018	0.52	0.52	0.51	0.51	
2019	0.49	0.49	0.49	0.49	
2020	0.47	0.47	0.47	0.46	
2021	0.45	0.45	0.45	0.44	
Sources: Authors' calculations, from raw data in CBO (2014), p. 21, and CBO (2016), p. 10					

all the data required by the methodology of this paper were available at the time of this writing. This suggested the need for a sensitivity analysis of the results obtained in the benchmark scenario considered by the paper, which assumes that economic agents expected that the reduction of government spending would be implemented in the terms implied by the Budget Control Act.

To that effect, two alternative scenarios were considered. In one of them, it was assumed that economic agents expected that the cuts would be half the size of those scheduled as of the beginning of each year, from 2013 to 2016, as documented in the corresponding column of Table 2. In the other scenario, it was assumed that households and firms perfectly anticipated the reduction of government expenditures that actually took place between 2013 and 2017 recorded in the last column of that table.

3 Overview of the Model Economy and Adapted BCA Approach

Given that the neoclassical growth model is in the background of the debate about the magnitude of the aggregate Frisch elasticity, the paper confines the specification of preferences, technology, and government policies to those in the class consistent with balanced growth, as characterized by King, Plosser, and Rebelo (1988a, b).

The arguments offered by Ljungqvist and Sargent discussed in the introduction suggest, however, that such an analytical framework will not be particularly useful to resolve the disputes about the value of that elasticity, unless it somehow incorporates features of the actual economies that distort the households and firms economic decisions, relative to those they would have made in a frictionless economy. These considerations led almost naturally to reformulate the neoclassical growth model with the BCA approach proposed by CKM.

As is well known, the approach was specifically designed to parsimoniously capture possibly empirically relevant frictions present in actual economies with ancillary variables or wedges that close the gaps that appear in optimality and equilibrium conditions when theoretical variables are replaced by their empirical counterparts. The paper takes seriously, therefore, the explicit advice in Chetty *et al.* (2013), implicit as well in the arguments by Ljungqvist and Sargent presented earlier, that incorporating wedges to the analysis may yield additional insights on the debate prompted by the many attempts to infer the aggregate labor supply elasticity with different methodologies and sources of evidence. In any case, it is worthwhile to highlight other advantages of the BCA approach specific to the purposes of this paper.

First, because the approach builds the model economy around the structural framework of the well-established neoclassical growth model, it addresses Attanasio's (2013) concern that the evidence examined by microeconomic studies might be misinterpreted without accounting for the general equilibrium effects of economic shocks and policy regime changes.

Second, related to the previous advantage, it explicitly incorporates the capital stock into the analysis and eliminates, therefore, a potential bias in the Frisch elasticity estimates from Chetty *et al.* (2013), whose measuring device is the model without capital accumulation proposed by Rogerson and Wallenius (2009). As is well known, intertemporal variations in the labor supply arise in part from deviations of the capital stock from its trend. Thus, one possible reason for the weak response of aggregate hours in Canada and Iceland in the policy episodes analyzed by Chetty *et al.* (2013) might be that those countries' capital stocks were above trend.

Third, as already mentioned, the BCA approach renders itself to a state-space representation of the model economy, which can be easily adapted to infer the aggregate Frisch elasticity value favored by the budget sequestration evidence with a methodology that draws its elements from the estimation and calibration points of view regarding the assignment of values to unknown model parameters.

A fourth advantage is that, by construction, the wedges introduced by the BCA approach replicate the data *exactly*, a feature that the methodology developed by the paper will exploit to rank the alternative Frisch elasticity values considered by their relative ability to account for the observed performance of macroecomomic variables during the budget sequestration period.

These advantages notwithstanding, the BCA approach as originally implemented by CKM wasn't quite appropriate for the purposes of this paper and had to be modified accordingly. One of the implementation details that needed to be adjusted was that those authors included net exports in their "government consumption wedge". This consolidation is inadequate for the methodology developed in this paper, given that its ability to extract the value of the aggregate Frisch elasticity most consistent with the evidence associated with the budget sequestration spending cuts will hinge critically on distinguishing the responses of macroeconomic variables to that policy shock from those induced by external sector shocks.

The need for that distinction forced the treatment of net exports as a different wedge. Although dictated by methodological considerations, a beneficial by-product of the separation of this wedge from the government spending wedge is the improvement of the mapping between the actual economy and model economy. The introduction in the latter of an external-like sector with the "minimalist" approach proposed by Trabandt and Uhlig (2011) captures, in an admittedly crude way, the interactions of the U.S. economy with the rest of the world that would have been much more challenging to model and parameterize explicitly.

Recall also that, for the reasons given in section 2.1 and discussed in more detail in section 3.1 below, the government spending wedge in the model economy measures the government absorption of private sector output, rather than government value added as in CKM.

The quantitative implementation of the analytical framework proposed above required also dealing with a number of issues regarding the measurement of variables and the specification of preferences and technology that, if not properly addressed, could have a detrimental impact on the assessment of the value of the aggregate Frisch elasticity most consistent with the evidence examined in this paper. Before getting into those rather technical details in the next section, it will be useful to provide a brief intuitive account of the economic mechanisms activated by the budget sequestration that will, in principle, allow the model economy and methodology developed in the paper to tease out the value of that elasticity from the evidence associated with that policy regime change.

As discussed in section 2.1, the reduction of government absorption of private sector output mandated by the Budget Control Act leaves more of that output available to households and firms. The standard wealth effect mechanism should induce a rise in consumption and leisure time when these variables are normal goods. As households reduce the fraction of time devoted to work, output falls. On the other hand, given the temporary nature of the decline of government absorption, the standard consumption-smoothing motive gives households the incentive to work and save more precisely during the time when less of the output they produce is taken away by the government. The net result of these forces in the general equilibrium framework of the model economy proposed above will depend on the values of the *labor-held-constant* intertemporal elasticity of consumption, of the aggregate Frisch elasticity, and of the parameters of the stochastic processes of the wedges. Alternative sets of values for those parameters, made statistically consistent with each other with calibration and/or estimation methods, will induce different configurations of the wedges during the budget sequestration period. The likelihood of those configurations, each associated with a particular value of the aggregate Frisch elasticity, can then be calculated to identify which is most favored by the responses of key macroeconomic variables to the spending cuts policy.

3.1 Measurement Issues

As repeatedly indicated, the inferences on the value of the aggregate Frisch elasticity obtained in this paper will be guided by the premise that the natural experiment characteristics of the spending cuts initiated in the U.S. in 2013 imparted on key macroeconomic variables responses that contained valuable information about that elusive value. Given the scarcity of such observable variables from which that information could be extracted with the adopted event study approach, it was important to take extra precautions to minimize as much as possible errors in measuring them. To that effect, the paper corrects in the manner discussed in this section measurement errors that are typically ignored in other macroeconomic studies, on the belief or certainty that they are largely inconsequential for the question being addressed or washed away by the many more observations available to answer it.

One source of those commonly overlooked errors is the lack of correspondence between the variables in the model economy and their empirical counterparts. The discrepancy should be of particular concern when government activities—in the form of reduction of government spending of goods and services in the present paper—play a critical role in the analysis, and the output originated in those activities represents a significant fraction of overall output. For the case of the U.S., that fraction was 19% on average over the period 1977-2007 considered to calibrate many of the parameters of the model economy. Such a percentage is large enough to distort estimates of the Frisch elasticity obtained with a model economy built on the assumption, as is the case of the one proposed in this paper, that the quantities of all types of goods and services produced and utilized in the actual economy reflect the interaction of optimizing private agents that value them at market prices, when in reality that is not the case of the mostly non-market activities typically conducted by government agencies.

Gomme and Rupert have proposed to mitigate this conceptual mismatch by adjusting the data in a manner consistent with the behavior of economic agents assumed in the model economy. Several steps are involved in this adjustment, but the one that is important to highlight for the purposes of this paper is that since the model economy assumes that all output is produced by profit-maximizing firms, the appropriate counterpart in the actual economy is constructed by subtracting from real GDP the value added by the government in the process of producing non-market goods and services. This "private sector economy" approach is not an obstacle to make inferences about the Frisch elasticity values from the responses of macroeconomic variables to the budget sequestration spending cuts because, as mentioned earlier, those cuts fell mostly on the government absorption of the goods and services produced by the private sector, rather than on the value added by the government, mostly made up by the compensation of the labor services provided by government employees.

The data necessary to obtain as just indicated the historical series of private sector output are available at an annual frequency only since 1977 and up to 2016 as of the time of this writing. The evidence examined in this paper pertains, therefore, to the period 1977-2016. Details on the data sources have been provided in Appendix A.

Further adjustments to the National Income and Product Accounts (NIPA) are necessary to make the data consistent with the conceptual entities in the model economy, but a thorough discussion of them is tedious and would detract from the main focus of the paper. Interested readers will be able to find the relevant details in the online supplementary material to Kydland and Zarazaga (2016).

The balanced-growth assumption required to make other types of adjustments to the data, unrelated to their possible contamination with measurement errors. In particular, that assumption imposes the restriction that all forms of technological progress must admit a labor-augmenting representation. For the reasons given in Greenwood, Hercowitz, and Krusell (1997), a necessary condition to meet that requirement is that the appropriate macroeconomic variables must be measured in units of the consumption good. This was accomplished by dividing the corresponding nominal variables counterparts by a price index of non-durable goods and services.

Furthermore, although the model economy is assumed to display total factor productivity and population secular deterministic growth, for computational reasons it was more convenient to represent it as an economy without growth. To that end, all variables that would otherwise display secular growth in the actual economy were detrended by the growth rate of total factor productivity and of the population 16 years of age and older. This transformation is inconsequential for the quantitative properties of the impulse-responses and transitional dynamics of the model economy.

In theory, labor input exhibits a stationary behavior along the balanced-growth path and doesn't need, therefore, to be detrended. In practice, however, that has not been the case in the U.S., where households have allocated on average a growing fraction of their available time to work between the end of the Second World War and the beginning of the 21st century. This theory-contradicting performance was largely the result of an increase in women's labor force participation rate that the economics profession has had a hard time attributing exclusively to economic factors. This upward trend reversed itself in the opposite direction, however, around the time the Great Recession struck in 2008, because by coincidence it was then that the disproportionately large generation of baby boomers started to reach retirement age and withdraw, therefore, from the labor market.

In the presence of those long-lasting swings of labor input, treating its trend as a constant value would have resulted in a serious mismeasurement of the deviations of this variable from its steady state. Leaving them untreated would have been detrimental for the accuracy of the inferences about the value of the aggregate Frisch elasticity drawn with the methodology developed by the paper, which includes those deviations in the vector of the observable variables used to that end.

In the absence of a clear guidance from theory, the underlying labor input trend was estimated by interpolating the trend implied by a Hodrick-Prescott filter and the demographically-adjusted labor input trend calculated by Zarazaga and Mihaylov (2018).

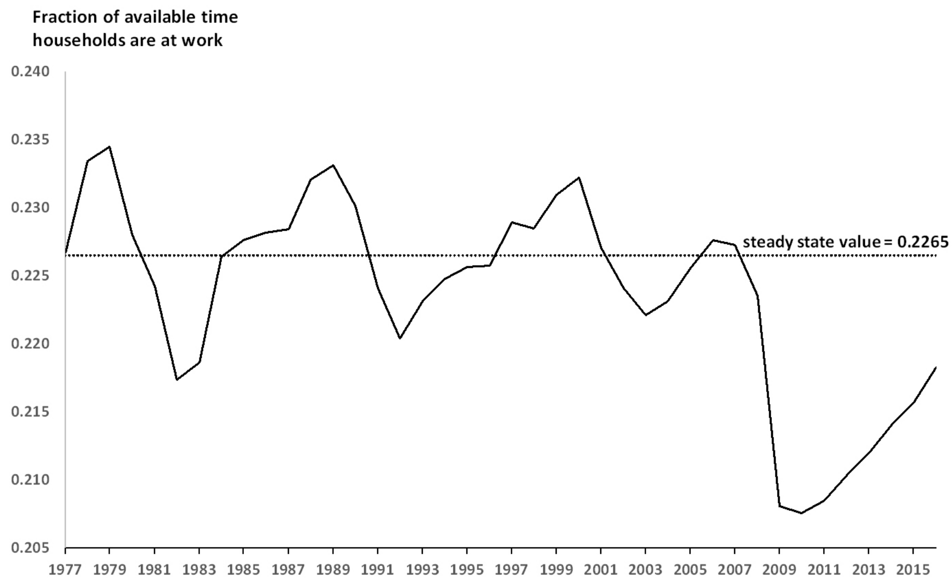
The application of the procedure required to estimate the steady-state value of the fraction of available time that households are at work, which was assumed to be 0.2265, the average for that fraction observed between 1948 and 2016. The resulting adjusted labor input series is documented in Figure 2.

3.2 Specification Issues

On the model specification front, the choice of the utility function representing the stand-in household's preference ordering over consumption and leisure was dictated by the convenience of minimizing as much as possible the approximation errors unavoidably emerging from the computation of the economic agents' decision rules with a first order perturbation technique.

For the reasons hinted at in the introduction, this consideration immediately ruled out the utility function specification adopted by Prescott (2004), which implies that the Frisch

Figure 2
Detrended Labor input (h_t)



elasticity is a function of the labor-held constant intertemporal substitution of consumption, labor income taxes when present and, importantly, the fraction of available time households devote to work. As a result, the perturbation computational method, which approximates the private sector's decision rules around the non-stochastic steady state, would automatically fix the value of that elasticity to the one determined by the steady value of the parameters just mentioned. In this case, meaningful inferences about the magnitude of the Frisch elasticity can only be obtained exploiting, as Prescott did, the different steady state fraction of time that households allocate to work in countries with different tax rates. There is nothing to be inferred, however, about the magnitude of that parameter when the available evidence is limited to that provided by the transitional dynamics of macroeconomic variables induced by a fiscal policy regime change, such as the one considered by this paper.[6]

It is to circumvent that "inference irrelevance" problem that the paper adopted the Constant Frisch Elasticity utility function specification, widely used in the macroeconomic

[6] It is for this reason that Ríos-Rull *et al.* (2012) question the usefulness of the utility functions considered by Prescott and others for measuring the willingness of households to substitute hours worked across time.

literature precisely because it breaks the tight link between the value of the Frisch elasticity and the fraction of time devoted to work in steady state, without losing the compatibility with balanced growth of the alternative utility function discussed in the previous paragraph.

In addition, to facilitate comparison of the results with those obtained by Chetty *et al.* (2013) and Prescott (2004), it was further assumed that preferences are separable in consumption and leisure, with the obvious implication that the conclusions of the paper will be conditional on the *leisure-held constant* intertemporal elasticity of substitution in consumption being equal to one.

4 The Model Economy

Having completed the motivation for the elements of the model economy in the previous section, it is appropriate to explain next how they are formally introduced into it.

4.1 The Stand-in Household's Choice Problem

The model economy is assumed to be inhabited by an infinitely-lived household, which stands for the large number of them present in the actual economy, and who ranks alternative streams of detrended consumption per working age member of the population, $\{c_t\}_t^\infty$, and leisure services, $\{l_t\}_t^\infty$, with the following time and state separable utility function in the Constant Frisch Elasticity class:

$$\ln(c_t) - \kappa(1 - l_t)^{1+\frac{1}{\varphi}},$$

where t stands for an index of discrete time, $t = 0, 1, ..., \infty$, $\kappa > 0$ is a parameter that controls the household's valuation of nonmarket productive time, and φ the constant aggregate Frisch elasticity.

The representative household is assumed to maximize the discounted sum of lifetime utility, subject to budget and physical capital accumulation constraints. Accordingly, it solves the following maximization problem:

$$\underset{\{c_t,\, h_t,\, k_{t+1}\}}{Max} E_s \sum_{t=s}^{\infty} \beta(1+\eta)^t \left[\ln(c_t) - \kappa(1-l_t)^{1+\frac{1}{\varphi}}\right], \tag{1}$$

subject to the following constraints:

$$\begin{aligned} c_t + x_t &= (1-\tau_t^h)w_t h_t + r_t k_t - \tau_t^k(r_t - \delta)k_t + ni_t + \tau_t, && (2)\\ x_t &= (1+\eta)(1+\gamma)k_{t+1} - (1-\delta)k_t, && (3)\\ 1 &= l_t + h_t, && (4)\\ h_t &= h_t^{pr} + h_t^{pu}, && (5)\\ & \text{government policies}, && (6)\end{aligned}$$

where $\beta > 0$ is the discount factor, η is the working age population annual growth rate, and h_t the fraction of available time allocated to work in the market, instead of to leisure or household production, l_t.

Equation (2) is the household's budget constraint, where x_t is gross private domestic investment, w_t the wage rate in terms of consumption per unit of the available time the stand-in household devotes to work, τ_t^h the tax rate on labor income, r_t the rental price of period t private sector capital, k_t, τ_t^k the tax rate on income from that capital, δ the depreciation rate, τ_t lump-sum transfers (taxes if negative), and ni_t net imports.

The variable ni_t captures the net exports wedge discussed in section 3, relabeled as "net imports" to take into account that the U.S. trade balance was mostly negative over the period of analysis. For consistency with the balanced-growth assumption, the ratio of this variable to private sector output is assumed to be characterized by an autoregressive stationary stochastic process of order one, with unconditional mean niy, autoregressive parameter ρ_{ni} and standard deviation σ_{ni}.

Note that from a BCA perspective, the variables τ_t^h and τ_t^k play the role of the labor and capital wedges introduced by CKM, with stochastic properties analogous to that of net imports. The unconditional mean, autoregressive parameter, and standard deviations of the labor wedge are denoted τ_{ss}^h, $\rho_{\tau h}$, and $\sigma_{\tau h}$, respectively. The analogous parameters for the capital wedge are denoted τ_{ss}^k, $\rho_{\tau k}$, and $\sigma_{\tau k}$, respectively.

Equation (3) describes the evolution over time of the capital stock that the household rents to private firms which, for consistency with the NIPA methodology, excludes the public sector capital stock. This law of motion links the private capital stock available for production at the beginning of a period, k_t, with the households' investment decisions during that same period, x_t, and with the private capital stock that will be available at the beginning of the following period, k_{t+1}. The multiplication of the latter by the gross growth rate factor $(1+\eta)(1+\gamma)$ is the result of the usual procedure to transform a model economy growing at a constant deterministic rate into one without growth.[7]

Equation (4) states the time constraint that the stand-in household can distribute its total available time, normalized to 1, among non-market activities, l_t, (generically labeled as "leisure") and work in the marketplace, h_t.

Equation (5) states that the household can allocate the time it devotes to work between private sector firms, h_t^{pr}, and public sector agencies (inclusive of government-owned enterprises), h_t^{pu}. Note that for consistency with the standard treatment of labor input in the neoclassical growth model, the empirical counterpart of the variable h_t is the fraction of time actually worked, not just paid. The data were therefore adjusted to omit the time for which workers were paid but not actually working, because they were on vacation, sick leave, etc.

[7] Recall that Greenwood, Hercowitz, and Krusell have demonstrated that in this case the depreciaton rate in (2) and (3) must be interpreted as the *economic*, rather than physical depreciation rate in the presence of not explicitly modeled investment-specific technological progress.

The explicit distinction between the time households devote to work in the public and private sectors is uncommon, because the value added by both the private and public sectors is deemed the appropriate empirical counterpart of output in most models. This is not true for the model economy of this paper, in which all the value added is provided by the private sector. Calibrating or estimating the relevant parameters of such an economy without taking into account the fraction of time that households work for government agencies could cause the model to overestimate the labor input hired by the private sector and, therefore, the output produced by it, with potentially nonnegligible consequential spillovers on other variables.

4.2 Private Sector Firms' Maximization Problem

There are two types of firms that produce output in the stationary economy without growth and without a government final good: private firms and government enterprises. As noted by Gomme and Rupert, the decisions of the latter are guided by administrative, rather than profit-maximizing considerations and are treated, therefore, as exogenous.

The behavior of private firms is instead modeled explicitly, an approach that requires one to be specific about the restrictions those firms face in the production of output.

The paper adopts the standard assumption that the model economy is populated by a large number of identical private firms that transform labor and capital inputs into output with a constant returns to scale technology that exhibits labor-augmenting technological progress and unitary elasticity of substitution between inputs. Under those conditions, the aggregate output of the model economy corresponds to that generated by a single representative firm endowed with a Cobb-Douglas production function:

$$y_t^{pr} = Ae^{(1-\theta)z_t} k_t^{\theta} (h_t^{pr})^{1-\theta}, \tag{7}$$

where y_t^{pr} is detrended output per working age person produced by private sector firms, θ the proportion of the remuneration to capital services in the private sector value added, and z_t a stochastic technology level that introduces the fourth wedge considered for the particular implementation of the BCA methodology proposed in this paper. This technology level shifter corresponds conceptually to the *efficiency wedge* in CKM.

The evolution of this wedge over time is assumed to be governed by the following autoregressive process:

$$z_t = \rho_z z_{t-1} + \sigma_z \varepsilon_t^z,$$

where $0 < \rho_z < 1$, where σ_z is a strictly positive scalar and ε_t^z a random variable with a standard normal distribution.

Given that the model assumes that investment decisions are made by the households, the representative firm that in the abstraction of the model stands for the large number of them making decisions in the actual economy solves the following static maximization problem:

$$\underset{h_t^{pr},\, k_t}{Max} \left[Ae^{(1-\theta)z_t} k_t^{\theta} (h_t^{pr})^{1-\theta} - w_t h_t^{pr} - r_t k_t \right]. \tag{8}$$

4.3 Public Sector Policies

As mentioned in section 3.1, the allocation of resources by public sector entities is the result of complex social, political, and economic considerations, not aptly captured by the same profit- and utility-maximizing incentives faced by households and private sector firms. Given the difficulties in modeling explicitly the behavior underlying the economic decisions made by public sector agencies, the variables under their control will be exogenously determined.

4.3.1 Government Budget Constraint and the Sequester

Most studies that estimate or infer the value of the Frisch elasticity with macroeconomic data or from the evidence provided by fiscal policy developments, as those already mentioned by Chetty *et al.* (2013), Prescott (2004), Ríos-Rull *et al.*, and Rogerson and Wallenius, assume a balanced government budget. To facilitate comparison with the results obtained in those studies, the paper adheres to that analytically and computationally convenient practice. Notice, however, that this assumption is not as restrictive as it seems in the context of this paper, because the labor and capital income wedges will indirectly capture the effects on the endogenous variables of the not explicitly model government debt trajectory.

With that caveat in mind, the government absorption of output exclusively produced by the private sector, denoted ga_t, is equal every period to revenues from all sources minus transfer payments, as indicated by the following government budget constraint:

$$ga_t = \tau_t^h w_t(h_t^{pr} + h_t^{pu}) - w_t h_t^{gc} + \tau_t^k(r_t - \delta)k_t + s_t^{ge} - \tau_t, \tag{9}$$

where h_t^{pu} is equal to $h_t^{gc} + h_t^{ge}$, with h_t^{gc} and h_t^{ge} representing the fraction of time the stand-in household works for government agencies and government-owned enterprises, respectively, and where s_t^{ge} denotes, for consistency with the NIPA methodology, surpluses (deficits, if negative) transferred by government-owned enterprises. In line with the treatment of variables corresponding to physical quantities discussed before, those of the same type in the government budget constraint are measured in units of the consumption good per working age population as well.

To avoid misunderstandings, recall that the variable ga_t is conceptually different from the government consumption expenditure variable in CKM, which in the case of those authors includes value added by the government sector and, as mentioned earlier, net exports.

Moreover, for the purpose of the present paper it is convenient to interpret this variable as made up of a systematic, exogenous stochastic component, ega_t, and of a non-systematic, deterministic component, pga_t, whose relationship, after division by private sector output, can be formally represented as follows:

$$\frac{ga_t}{y_t^{pr}} = \frac{ega_t}{y_t^{pr}} + \frac{pga_t}{y_t^{pr}}. \tag{10}$$

In line with the historical developments described in section 2.1, the stochastic component ega_t is meant to capture the ups and downs of the government spending policy historically followed until the sequestration took place in 2013. The non-systematic, deterministic component pga_t is meant to capture the "policy regime change" of limited duration (from 2013 to 2021, to be precise) implied by the budget sequestration spending cuts.

For consistency with the balanced growth assumption, the stochastic component is postulated to evolve over time according to a stationary stochastic process with the following autoregressive representation:

$$\ln \frac{ega_t}{y_t^{pr}} = (1 - \rho_{ga}) \ln gy + \rho_{ga} \ln \frac{ega_{t-1}}{y_{t-1}^{pr}} + \sigma_{ga} \varepsilon_t^{ga}, \tag{11}$$

where $0 < \rho_{ga} < 1$, gy and σ_{ga} are strictly positive scalars, and ε_t^{ga} is a random variable with a standard normal distribution.

The policy component in (10), $\frac{pga_t}{y_t^{pr}}$, is a placeholder that will be replaced in the quantitative implementation of the model, as explained in section 5.2.2, by the scheduled spending cuts listed in Table 2, with the practical effect of shifting down the government absorption of private sector output relative to the level implied by the exogenous component $\frac{ega_t}{y_t^{pr}}$.

4.3.2 Public Sector Labor Demand

In line with the pattern of the previous stochastic process, the general government and government enterprises' demand for labor services is also assumed to be governed by an autoregressive stochastic process, with the following representation:

$$\ln h_t^{pu} = (1 - \rho_{hpu}) \ln h_{ss}^{pu} + \rho_{hpu} \ln h_{t-1}^{pu} + \sigma_{hpu} \varepsilon_t^{hpu} \tag{12}$$

where $0 < \rho_{hpu} < 1$, h_{ss}^{pu} and σ_{hpu} are strictly positive scalars and ε_t^{hpu} is a random variable characterized by a standard normal distribution.

4.3.3 Government Enterprises Value Added

The value added by government enterprises, va_t^{ge}, included in the business rather than the government sector of NIPA, should grow at the same rate as private sector output along a balanced growth path. Therefore, it is natural to postulate that the evolution of this variable over time is determined by the following stochastic process:

$$\ln \frac{va_t^{ge}}{y_t^{pr}} = \ln vy + \sigma_{ge} \varepsilon_t^{ge} \tag{13}$$

where vy and σ_{ge} are scalars, and ε_t^{ge} is a random variable characterized by a standard normal distribution.

4.3.4 Resource Constraint

For the purpose of subsequent analysis, it is useful to make explicit the resource constraint that results from consolidating the household's budget constraint (2) with the government budget constraint (9), after taking into account that, for consistency with the NIPA methodology, output in the model economy originates in private sector firms according to (7) and in government-owned enterprises according to (13):

$$c_t + x_t = \left[1 + \frac{va_t^{ge}}{y_t^{pr}} - \frac{ga_t}{y_t^{pr}} + \frac{ni_t}{y_t^{pr}} \right] A e^{(1-\theta) z_t} k_t^{\theta} (h_t^{pr})^{1-\theta}. \tag{14}$$

4.4 Model Calibration

As is apparent from the preceding section, the model economy involves a fairly large number of parameters. Attempting to estimate all of them with available statistical tools at an acceptable level of precision is doomed to failure given the limited available data, at most 40 annual observations, from 1977 to 2016, the period for which, as indicated in section 3.1, all the observable variables relevant for the analysis were available at the time of this writing. It seemed wise, therefore, to calibrate as many parameter values as possible with the widely accepted quantitative discipline imposed by the requirement that the steady state economic relationships between variables and/or parameters predicted by the model economy should match those prevailing in the actual economy, on average, over fairly long periods of time.

The parameters of the model economy whose values were set with a calibration approach are listed in Table 3.

Table 3: Calibrated parameters and corresponding values

Parameter/Variable	**Value**
η (working-age annual population net growth rate)	0.0072
γ (TFP annual net growth rate)	0.0078*
δ (depreciation rate)	0.0676*
x/y^{pr} (investment-output ratio)	0.2121*
gy (fraction of private sector output absorbed by general government)	0.0825*
vy (government enterprises value added–private sector output ratio)	0.0156*
σ_{ge} (standard deviation of $\ln(va_t^{ge}/y_t^{pr})$)	0.0856*
niy (net imports–private sector output ratio)	0.026*
h_{ss}^{pr} (fraction of time worked in private sector)	0.20
h_{ss}^{pu} (fraction of time worked in public sector)	0.0265*
θ (private capital income share)	0.38
ρ_{hpu} (autoregression coefficient of stochastic process for h_t^{pu})	0.8493
σ_{hpu} (standard deviation of stochastic process for h_t^{pu})	0.009
y_{ss}^{pr} (steady-state private sector output)	1*
τ_{ss}^{k} (capital income tax rate)	0.35
τ_{ss}^{h} (labor income tax rate)	0.23

The values with an asterisk in the second column of the table denote the average value of the corresponding variable over the period 1997-2007. Observations during and after the Great Recession were deliberately omitted, on the grounds that the large changes that many macroeconomic variables experienced during that unusually deep contraction were persistent, but not permanent, and didn't have an everlasting impact, therefore, in the long run trends of the actual economy.

The parameter capturing the working-age population growth rate, η, was set to the long run value projected by the U.S. Bureau of the Census.

The autoregression coefficient and standard deviation of the stochastic process governing the evolution of the fraction of time households work in the public sector, h_t^{pu}, was obtained by running the regression suggested by equation (12), using the values of that variable for the period 1977-2007, previously adjusted by a time trend that takes into account the rather consistent decline that h_t^{pu} has exhibited since the end of the 1960s.

The resulting detrended values of h_t^{pu} were subtracted from the series of aggregate detrended labor input h_t inferred with the procedure discussed in section 3.1, in order to obtain the detrended series of private sector labor input, h_t^{pr}.

The capital share parameter θ, the steady-state capital income tax rate, τ_{ss}^k, and the steady-state labor income tax rate, τ_{ss}^h, were set to the values that Kydland and Zarazaga deemed most consistent with the relevant historical evidence for the U.S.

Other parameters that will appear in equilibrium conditions were obtained by replacing the values calibrated in Table 3 in the appropriate steady state relationships.

Thus, the steady state capital-output ratio, 2.5681, was obtained from the steady state version of the law of motion of capital (3). The discount factor β was set to the value of 0.9578 implied by the steady state version of the Euler equation:

$$\beta = \frac{1+\gamma}{1+\left(1-\tau_{ss}^k\right)\left(r_{ss}-\delta\right)},$$

where the steady state level of the rental price of capital, r_{ss}, was set to the value of 0.148 implied by the steady state relationship $r_{ss} = \theta/(k/y^{pr})$.

It is worth pointing out that the steady state level of private sector output, 1, coincides with the average value of output over the period 1977-2007, after normalizing the actually observed series of that variable with the appropriate constant implied by the production function (7).

Missing from Table 3 are also model parameters that can only be inferred from the high frequency movements of the economic variables under their influence, by definition absent from steady state relationships. Parameters of this type fall in three groups: 1) the coefficients of stationary stochastic processes that drop out from the model equations in steady state, 2) the aggregate Frisch elasticity, φ, and 3) parameters whose steady state values depend on the latter.

The parameters in the first group were estimated with the techniques discussed in the next section.

Recall that the goal of the paper is to scrutinize which of the rather diverse Frisch elasticity values claimed to be empirically relevant in existing studies can best account for the dynamics of macroeconomic variables induced by the budget sequestration. To that end, the paper considers the following five values, representative of those advocated by some and disputed by others in the literature:

$$0.5,\ 1.0,\ 1.4,\ 1.9,\ \text{and}\ 3.0.$$

The first Frisch elasticity value stands for the point estimate of 0.52 for that parameter obtained by Smets and Wouters (2007) in a study pioneering the estimation of dynamic stochastic general equilibrium models with Bayesian techniques.[8] The value of 1.0 is suggested by the survey evidence on the response of labor supply to a large wealth shock examined by

[8]See endnote 30 of Chetty *et al.* (2013) clarifying that the value of 1.92 reported by Smets and Wouters is actually the reciprocal of the aggregate Frisch elasticity.

Kimball and Shapiro (2008). The value of 1.4 is that which Lucas and Rapping estimated in their already cited pioneering paper. The value of 1.9 has been proposed by Hall (2009) in a study that includes a labor wedge. The value of 3.0 has been inferred by Prescott (2004) from the study on labor income tax differences across countries mentioned earlier.

As to the third group of parameters, they include those that are implied by steady state relationships that depend, precisely, on the values of the Frisch elasticity. That is the case of the utility function parameter κ, whose value is reset for each of the five Frisch elasticity values considered, to recover the steady state level of labor input, h_{ss}, from the corresponding steady state version of the intratemporal first order necessary condition implied by the household's maximization problem.

5 Quantitative Methodology

This section is devoted to describe in detail the methodology that the paper designed with the explicit purpose of establishing which of several existing estimates of the aggregate Frisch elasticity are more consistent with the response of key macroeconomic variables to the budget sequestration spending cuts launched in 2013. It will also serve the purpose of conveying the sense in which the methodology performs that task by blending elements of the estimation and calibration traditions.

5.1 Overview

As anticipated in the introduction, the quantitative implementation of the BCA approach, adapted to the purposes of the paper, involves two stages, an "estimation stage" and a "calibration stage."

The estimation stage exploits the state-state representation of the equilibrium conditions of the model economy to estimate unknown states and parameters with a rather standard maximum likelihood implementation of the Kalman filter. Given that the likelihood of the data is conditional on parameter values, this estimation stage had to be repeated for each of the five Frisch elasticity values listed in section 4.4.

Considering that the debate about the value of the aggregate labor supply elasticity has been largely driven by divergent opinions about the nature of the business cycles, it was deemed worthwhile to document and briefly discuss the business cycle statistics implied by each of the five sets of statistically consistent state and parameter estimates, indexed by the corresponding assumed value for the Frisch elasticity parameter, obtained in the estimation stage.

The analysis of those business cycle statistics suggested what the goal of the second stage of the methodology should be: to check if the observed responses of macroeconomic variables to the budget sequestration policy shock are more likely to have been observed for the parameter estimates associated with Frisch elasticity values that magnify the ability of TFP shocks to account for economic fluctuations at business cycle frequencies, or rather, for parameter estimates corresponding to Frisch elasticity values that diminish that ability.

As hinted at in the introduction, the execution of this stage required to take into account the economic agents' new decision rules, incorporating the policy regime change represented by the sudden materialization of the spending cuts. The basic idea behind the design of this second stage is that the different decision rules implied by the alternative sets of parameters estimated in the first stage, each indexed by one of the five Frisch elasticity considered, will induce different responses to the spending cuts and, therefore, a different configuration of the innovations to the wedges necessary to replicate exactly the available observable variables in the measurement equations of the state-space representation of the model during the budget sequestration period.

It follows that the higher the likelihood of those observables, the more likely the combination of parameter estimates and updated unobserved states underlying the corresponding decision rules to account for the joint performance of macroeconomic variables while that policy was in place. It seems logical to propose that, for the purpose of discerning the nature of economic fluctuations at business cycle frequencies implied by the model economy, unknown states and parameter values should be "calibrated," according to the formal metric long-demanded by the estimation school of thought, to that set of first stage estimates, and corresponding assumed Frisch elasticity value, that delivers the highest value of the likelihood of the observables during the budget sequestration. Because the proposal certainly satisfies the independent validation of parameter values advocated by the calibration approach, it seems fair to interpret it as the "calibration stage" of the methodology described in more detail next.

5.2 State-Space Representation

The first step in implementing the adapted BCA approach is to represent the model in a state-space form, which is accomplished as usual, by specifying transition equations that govern the evolution of state variables over time and measurement equations that define the mapping between the states and the relevant observed data.

In dynamic stochastic general equilibrium models, the link between observables and state variables in the measurement equations is provided by the equilibrium decisions rules which, as already anticipated, this paper computes with the standard practice of approximating the true decision rules with a first order Taylor expansion around the non-stochastic steady state. This ensures a linear mapping between state variables and observables.

With the further assumption that the transition from one state to the other is governed by a linear Markov process, the state-state representation of the model economy of this paper can be formalized by the *transition equation:*

$$S_t = TS_{t-1} + Q\omega_t, \tag{15}$$

and the *measurement equation:*

$$Y_t = DS_{t-1} + C\omega_t. \tag{16}$$

To see how the different pieces of the model economy fit together in the state-space representation above, it will be helpful to spell out more fully the elements of the vectors and matrices in equations (15) and (16), starting with the $7x1$ vector S_t of end-of-period t state variables in the transition equation,

$$S_t = [k_{t+1} - k_{ss},\ \ln \frac{ega_t}{y_t^{pr}} - \ln gy,\ \ln h_t^{pu} - \ln h_{ss}^{pu},\ \ z_t - z_{ss},\ \frac{ni_t}{y_t^{pr}} - niy,\ \ \tau_t^h - \tau_{ss}^h,\ \tau_t^k - \tau_{ss}^k]',$$

where a subindex "ss" identifies the steady state value of the period t variable immediately to the left[9].

Consider next the $7x7$ matrix T:

$$T = \begin{bmatrix} T_{11} & T_{12} & T_{13} & T_{14} & T_{15} & T_{16} & T_{17} \\ 0 & \rho_{ga} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_{hpu} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_z & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_{ni} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \rho_{\tau h} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \rho_{\tau k} \end{bmatrix},$$

where the first row of this matrix is simply the result of replacing in the law of motion for the private capital stock, (3), the equilibrium decision rule for investment, x_t. The second and third rows of the matrix simply replicate the stochastic processes in equations (11) and (12), respectively. The rest of the rows of this matrix represent the wedges, expressed in terms of ratios to private sector output when appropriate, as stochastic Markovian processes

[9] For consistency with the timing convention adopted in the law of motion of capital (3), the capital stock at the end of period t is denoted in the vector S_t as the beginning of period $t+1$ capital stock, k_{t+1}.

that depend only on their own past. Interactions between these processes were ruled out by assumption, for the same reasons given earlier: the limited data available would have prevented the reliable estimation of the large number of parameters implied by a less parsimonious specification.[10]

The elements of the $7x1$ vector of exogenous shocks ω_t are as follows:

$$\omega_t = [\varepsilon_t^{ga},\, \varepsilon_t^{hpu},\, \varepsilon_t^{ge},\, \varepsilon_t^{z},\, \varepsilon_t^{ni},\, \varepsilon_t^{\tau h},\, \varepsilon_t^{\tau k}]',$$

where the first three elements correspond to the innovations identified in equations (11), (12), and (13), and the remaining elements capture the innovations to the four wedges z_t, ni_t, τ_t^h, and τ_t^k. The variance-covariance matrix of this vector, $E[w_t w_t']$, is denoted by Σ and characterized by the following elements:

$$\sum = \begin{bmatrix} \Sigma_{11} & 0_{3x4} \\ 0_{4x3} & \Sigma_{22} \end{bmatrix},$$

where Σ_{11} is a $3x3$ identity submatrix, and Σ_{22} a $4x4$ submatrix, with diagonal elements equal to 1 and possibly non-zero off-diagonal elements. This specification assumes that the stochastic process for the government absorption of private sector output, characterized by equation (11), as well as that for the public sector labor input, characterized by equation (12), are orthogonal to all the others, whereas the innovations to the wedges are allowed to be correlated with each other.

[10] It is not clear, in any case, that the interactions would be significant, as they are not statistically different from zero in CKM.

Fully spelled out, the $7x7$ matrix Q is given by

$$Q = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} & Q_{15} & Q_{16} & Q_{17} \\ \sigma_{ga} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sigma_{hpu} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sigma_z & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma_{ni} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma_{\tau h} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma_{\tau k} \end{bmatrix},$$

where the elements of the first row are coefficients implied by the linearized equilibrium decision rule for the capital stock and the rest of the elements just capture the standard deviations of all the exogenous stochastic processes in the model.

In the measurement equation, the $7x1$ column vector Y_t contains the observable variables:

$$Y_t = [y_t^{pr} - y_{ss}^{pr},\, x_t - x_{ss},\, h_t^{pr} - h_{ss}^{pr},\, \ln \frac{ega_t}{y_t^{pr}} - \ln gy,\, \ln h_t^{pu} - \ln h_{ss}^{pu},\, \ln \frac{va_t^{ge}}{y_t^{pr}} - \ln vy,\, \frac{ni_t}{y_t^{pr}} - niy]',$$

where again a subindex "ss" identifies the steady state value of the corresponding variable.

The $7x7$ matrix D can be rewritten as

$$D = \begin{bmatrix} & & & \mathbb{D}_{3x7} & & & \\ 0 & \rho_{ga} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_{hpu} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho_{ni} & 0 & 0 \end{bmatrix},$$

where the elements $\mathbb{D}_{ij}$ of the $3x7$ submatrix $\mathbb{D}$ consist of the coefficients of the linearized equilibrium decision rules for the endogenous variables in the vector Y_t, and the non-zero elements in the last four rows capture the autoregressions coefficients of the stochastic processes for government absorption of private sector output, public sector labor input, and net imports.

Finally, the $7x7$ matrix C is given by

$$C = \begin{bmatrix} & & \mathbb{C}_{3x7} & & & & \\ \sigma_{ga} & 0 & 0 & & & & \\ 0 & \sigma_{hpu} & 0 & & 0_{3x4} & & \\ 0 & 0 & \sigma_{ge} & & & & \\ 0 & 0 & 0 & 0 & \sigma_{ni} & 0 & 0 \end{bmatrix},$$

where the elements $\mathbb{C}_{ij}$ of the $3x7$ submatrix $\mathbb{C}$ are obtained from the equilibrium decision rules and the last four rows contain the standard deviations of the stochastic processes for government absorption, public sector labor input, government enterprises value added, and net imports.

Having made explicit the mapping between the model economy in section 4 and its state-space representation in this one, it is possible to proceed with the second step to estimate the unknown state variables and parameters of the model.

5.2.1 Estimation Stage

The parameters not listed in Table 3 or which could not be derived from them exploiting steady-state relationships were estimated using annual data for the period 1977-2012. As already mentioned in section 3.1, 1977 is the first year for which the data necessary for the "private sector output approach" implemented by the paper is available. The data after 2012 reflected the effects of the budget sequestration policy regime change and were therefore excluded from the estimation stage, to respect the calibration discipline in the design of the methodology proposed by the paper.

It seemed reasonable, however, to include the observations between 2008 and 2012, that is, for the Great Recession and its aftermath, because that contraction was characterized, by most accounts, by the virulent manifestation of several frictions. Those observations might contain, therefore, information particularly useful for estimating the parameters of the stochastic processes of the wedges meant to summarily capture those frictions in the model.

The resulting sets of estimates of the state variables, autoregression coefficients, and variances and covariances, one for each of the five Frisch elasticity values considered, were assumed to characterize the joint distribution of the stochastic variables that will enter in the calculation of the likelihood of observables in the subsequent calibration stage of the methodology.

The estimates of the parameters of the exogenous stochastic processes, indexed by the assumed Frisch elasticity value, are documented in Table 4.

In any case, the estimated parameter values are of less interest than their implications for the nature of the business cycle that is in the background of the debate about the magnitude of the Frisch elasticity. In fact, given that they provided the motivation for the calibration stage of the methodology that will be discussed later, the business cycle statistics implied by each estimated combination of estimated parameters is briefly summarized and discussed next.

Business Cycle Properties of the Model Economy Table 5 reports conventional business cycle statistics for the actual economy and those predicted by the model economy for four sets of parameter estimates, indexed by the corresponding assumed aggregate Frisch elasticity, representative of the five such sets identified in the previous section.

The upper panel of the table documents the standard deviations, in percentage points, corresponding to the variables or metric listed in the first column, while the lower panel

Table 4: Estimated parameters for given Frisch elasticity value

Parameter	Frisch elasticity value for estimation set at:														
	0.5			1.0			1.4			1.9			3.0		
	Estimate	Standard Deviation	t-Statistic	Estimate	Standard Deviation	t-Statistic	Estimate	Standard Deviation	t-Statistic	Estimate	Standard Deviation	t-Statistic	Estimate	Standard Deviation	t-Statistic
ρ_z	0.9046	0.0540	16.7443	0.9014	0.0542	16.6284	0.9002	0.0541	16.6250	0.8994	0.0540	16.6510	0.8986	0.0537	16.7317
ρ_{ni}	0.9400	0.0524	17.9540	0.9325	0.0513	18.1704	0.9286	0.0511	18.1807	0.9253	0.0510	18.1568	0.9212	0.0509	18.1035
$\rho_{\tau h}$	0.9032	0.0776	11.6467	0.8894	0.0799	11.1367	0.8843	0.0792	11.1674	0.8813	0.0778	11.3312	0.8792	0.0750	11.7232
$\rho_{\tau k}$	0.9737	0.0302	32.2548	0.9763	0.0275	35.4572	0.9770	0.0266	36.7522	0.9773	0.0260	37.5735	0.9773	0.0256	38.2338
ρ_{ga}	0.8716	0.0586	14.8734	0.8684	0.0590	14.7281	0.8667	0.0591	14.6527	0.8652	0.0593	14.5864	0.8632	0.0596	14.4956
σ_z	0.0217	0.0026	8.3846	0.0217	0.0026	8.3712	0.0217	0.0026	8.3680	0.0217	0.0026	8.3666	0.0217	0.0026	8.3678
σ_{ni}	0.0069	0.0008	8.5320	0.0069	0.0008	8.5252	0.0069	0.0008	8.5208	0.0069	0.0008	8.5161	0.0069	0.0008	8.5090
$\sigma_{\tau h}$	0.0385	0.0045	8.5028	0.0249	0.0029	8.4824	0.0211	0.0025	8.4785	0.0187	0.0022	8.4783	0.0162	0.0019	8.4820
$\sigma_{\tau k}$	0.0201	0.0049	4.0662	0.0195	0.0042	4.6602	0.0194	0.0039	4.9150	0.0194	0.0038	5.0819	0.0194	0.0037	5.2232
σ_{ga}	0.0395	0.0047	8.4274	0.0395	0.0047	8.4172	0.0395	0.0047	8.4113	0.0395	0.0047	8.4062	0.0396	0.0047	8.3988

Table 5: Data and model business cycle statistics

Variable or Statistical Metric	Data	Frisch elasticity = 0.50				Frisch elasticity = 1.4				Frisch elasticity = 1.9				Frisch elasticity = 3.0			
STANDARD DEVIATION (in %)																	
		Model predicted, for each combination of parameter estimates associated with set Frisch elasticity value and wedge															
		Wedge				Wedge				Wedge				Wedge			
		TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)
y^{pr}	2.02	1.32	1.12	0.20	0.15	1.47	1.18	0.32	0.26	1.52	1.20	0.36	0.30	1.58	1.24	0.41	0.34
c	1.63	0.69	0.58	0.62	0.51	0.74	0.57	0.55	0.42	0.76	0.57	0.53	0.40	0.78	0.58	0.51	0.37
h^{pr}	1.87	0.25	1.83	0.27	0.24	0.48	1.92	0.49	0.42	0.56	1.96	0.56	0.48	0.67	2.02	0.65	0.55
x	6.68	3.72	3.16	2.79	0.38	4.23	3.47	3.12	0.18	4.40	3.58	3.25	0.11	4.63	3.72	3.43	0.01
$\frac{y^{pr}}{h^{pr}}$	0.76	1.09	0.74	0.20	0.09	1.01	0.78	0.27	0.16	0.99	0.79	0.30	0.18	0.95	0.82	0.34	0.21
Sum Data-Model Squared Deviations		12.82	14.25	22.27	***47.43***	9.02	12.08	18.80	49.17	7.94	11.40	17.62	49.81	***6.55***	***10.48***	***15.98***	50.82

Variable or Statistical Metric	Data	Frisch elasticity = 0.5				Frisch elasticity = 1.4				Frisch elasticity = 1.9				Frisch elasticity = 3.0			
CORRELATION ($h^{pr}, \frac{y^{pr}}{h^{pr}}$)																	
		Model predicted, for each combination of parameter estimates associated with set Frisch elasticity value and wedge															
		Wedge				Wedge				Wedge				Wedge			
		TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)	TFP (z)	Labor (τ^h)	Capital (τ^k)	Net Imports (ni)
Correlation ($h^{pr}, \frac{y^{pr}}{h^{pr}}$)	0.005	0.947	-0.974	-0.660	-0.974	0.924	-0.973	-0.792	-0.999	0.915	-0.973	-0.816	-0.999	0.900	-0.973	-0.841	-1.000

provides the correlation between hours worked and labor productivity, given the special attention that these statistics have received in the literature discussing the empirical relevance of different interpretations of the business cycle. The significance of the content of each panel of the table for the purpose of the paper is discussed separately next.

As to the first panel, the second column documents the percent standard deviation of the variables in the first column for the actual economy, calculated with HP-filtered annual data for the period 1977-2007.[11] The observations from 2008 onwards were excluded, to avoid contaminating the reported business cycle statistics with the abnormally large deviations that most macroeconomic variables exhibited from their trends during the Great Recession and its aftermath. The entries in the first five rows of the remaining columns report, for each set of state and parameter estimates, indexed by the corresponding assumed aggregate Frisch elasticity value, the percentage standard deviation of the variables in the model economy induced by the wedge indicated in the respective column heading, under the assumption that the other wedges are inactive. These statistics were obtained by simulating the model for 31 periods with 2000 replications.

The entries in the sixth line of the first panel, borrowed from the method of simulated moments, reports the squared sum of the differences between the observed standard deviations of the variables considered and those predicted by each of the wedges for each set of parameter estimates. The numbers in bold identify the Frisch elasticity value and associated parameter estimates that minimizes this metric for each wedge. By this criterion, the highest aggregate Frisch elasticity value among those considered, 3.0, is the one for which the efficiency, labor, and capital wedges account best for the overall fluctuations of the actual economy according to the metric just described.

The table also confirms the theoretical prediction that the larger the value of the Frisch elasticity, the larger the fraction of the standard deviation of time devoted to work in the

[11] Following standard practice for data at annual frequency, the smoothing parameter of the filter was set to the value of 100.

private sector accounted for by the TFP shocks. In fact, when the Frisch elasticity is assigned the value of 3.0, TFP shocks can account for about 36% of the standard deviation of private sector labor input, a percentage about three times higher than when the Frisch elasticity value is just 0.5.

The lower panel in Table 5 documents the correlation between the fraction of time devoted to work in the private sector and labor productivity of that sector. Since the latter is proportional to the real wage in the frictionless neoclassical growth model, this correlation is a matter of contention in the literature. In particular, the fact that the "TFP shocks only" model economy predicts that this correlation is large, when it is almost nil in the data, is often exhibited as a severe enough counterfactual to drop TFP from the list of plausible sources of the business cycle.

Upon further inspection, however, it stands out that the counterfactual implication applies to all of the wedges. Moreover, inclusion of the squared deviation of the observed correlation under examination from the actual one predicted by each wedge on its own would not change the finding reported above: the resulting expanded method of simulated moments distance would still identify the combination of parameters estimates corresponding to the aggregate Frisch elasticity value of 3.0 as the one that enhances the most the role of the TFP shocks, or "efficiency wedge" in the BCA jargon, in the business cycle.

According to the calibration principle, however, the fact that such a large value of the Frisch elasticity is particularly favorable to the hypothesis that TFP shocks are an important source of economic fluctuations is not a good enough argument to adopt it in studies of the nature of those fluctuations. Independent validation with an unrelated phenomenon is required.

It was precisely in the pursuit of that independent validation that Prescott (2004) and Chetty *et al.* (2013) calibrated the aggregate Frisch elasticity to fiscal policy related evidence mentioned earlier. The contrast between the high elasticity value of 3.0 inferred by the

Prescott and the much smaller one of 0.75 obtained by the other authors suggested, given the quantitative significant consequences of the discrepancy, that the present paper should take advantage of the quasi-experimental nature of the budget sequestration spending cuts to report the readings of that elasticity most consistent with the responses of macroeconomic variables to that fiscal policy regime change. The next section is precisely devoted to explain how that challenge is confronted, in the spirit of independent validation principle sponsored by the calibration approach, with a metric that at the same time meets the measurement standards of the estimation school of thought.

5.2.2 Calibration Stage

Incorporating The Budget Sequestration Spending Cuts As mentioned earlier, the second stage of the methodology developed by the paper had to take into account that, once economic agents became aware in 2013 that the budget sequestration would materialize, their optimal decision rules were influenced not only by the 2013 prescribed spending cuts, but also by the future ones through 2021. This required the modification of the equilibrium decision rules of the estimation stage, which depended only on the previous period state variables. To that end, the new decision rules need to be recomputed with an algorithm that incorporated their dependence on non-stochastic policy regime changes the economic agents expected to be in effect in the future. The general principle behind such an algorithm in the context of perturbation methods is to treat perfectly anticipated current and future deviations of a policy variable from its steady state value as exogenous deterministic state variables and approximate the decision rules around the steady state with standard perturbation methods.

In the case of the spending cuts under study, the algorithm involves adding nine deterministic state variable, one for each of the years in the period 2013-2021 over which the spending cuts mandated by the Budget Control Act would remain in effect, and modifying the state-space representation of the model accordingly, as follows:

$$S_t = TS_{t-1} + Q\omega_t + \mathcal{M}\Delta_t, \tag{17}$$

$$Y_t = DS_{t-1} + C\omega_t + \mathcal{B}\Delta_t, \tag{18}$$

for $t = 2013, 2014, 2015, 2016$ and where Δ_t is a $9x1$ column vector whose elements capture the sequence of anticipated spending cuts and $\mathcal{M}$ and $\mathcal{B}$ are conformable matrices, with dimensions $7x9$.

Notice that the matrices T, D, C, and Q are the same as those obtained in the estimation stage because, by the arguments in section 2.2, the spending cuts prescribed by the Budget Control Act were temporary in nature and, therefore, inconsequential for the steady-state equilibrium of the model. Thus, the terms of the decision rules involving state variables that were already present in the model do not change, an implication consistent with setting the relevant parameters, including the elements of the matrix Q, equal to the values obtained in the estimation stage.

The effect of the budget sequestration spending cuts on the decision rules is captured additively, by the elements in $\mathcal{M}\Delta_t$ and $\mathcal{B}\Delta_t$, where Δ_t represents the deviations of the foreseen sequence of current and future spending cuts from their steady state value, which the preceding paragraph implies is zero. Notice that the spending cuts are entered with a positive sign because, according to equation (14), they add to the resources the private sector can devote to consumption and investment.

The fact that the time index ranges from the year 2013 to the year 2016 conveys the message that the second stage of the methodology involves keeping track of the responses of the observables in the vector Y_t to the spending cuts in the vector Δ_t from the time they were launched, in 2013, to 2016, the last year for which the data for all the observables in that vector were available at the time of this writing.

For the reasons given in section 2.2, it was deemed convenient to let the elements of Δ_t capture three different scenarios: one in which economic agents expected the spending cuts to be carried out exactly as prescribed by the 2011 Budget Control Act, a second scenario in which they expected that only half the size of the future spending cuts mandated by the relevant legislation at the beginning of each year would be actually implemented and finally, a third scenario in which economic agents made their decisions every year between 2013 and 2016 perfectly anticipating the actually materialized spending cuts, until canceled altogether, as mentioned in that section, by the Tax Cuts and Job Acts of 2018.

For clarity of exposition, it will be convenient to spell out the elements of the vector Δ_t for three different scenarios, denoted by a superscript $m = F, H, A$, keeping in mind that the steady-state private sector output has been normalized to one and that the prescribed spending cuts in percentage terms of that output documented in Table 2 need to be divided, accordingly, by 100.

In the case of the full credibility scenario, the elements of the vector Δ_t^F for the year 2013 are the statutory spending cuts listed in the second column of Table 2, that is,

$$\Delta_{2013}^F = \frac{1}{100}[0.24,\ 0.50,\ 0.54,\ 0.55,\ 0.54,\ 0.52,\ 0.49,\ 0.47,\ 0.45]'.$$

Since the methodology of the paper requires the evaluation of the responses of macroeconomic variables predicted by the model to the spending cuts scheduled as of the beginning of each year, the elements of the column vectors Δ_{t+1}^F, $t = 2013$, need to be updated with the figures of the corresponding column in Table 2, adding zeros at the end as needed to preserve the $9x1$ dimensions of the vector. Thus, for example, the column vector Δ_{2014}^F is spelled out as follows, after extracting its elements from the third column of that table:

$$\Delta_{2014}^F = \frac{1}{100}[0.25,\ 0.43,\ 0.55,\ 0.54,\ 0.52,\ 0.49,\ 0.47,\ 0.45,\ 0]'.$$

The spending cuts vectors for the subsequent year, Δ^F_{2015} and Δ^F_{2016} are constructed in a similar fashion.

An entirely analogous procedure applies to the scenario in which only half of the prescribed cuts are expected to be implemented. That is, the vector of spending cuts Δ^H_t, for $t = 2013, 2014, 2015, 2016$, is obtained from the equality $\Delta^H_t = \frac{1}{2}\Delta^F_t$.

As for the scenario for which economic agents perfectly foresaw the spending cuts actually implemented, the elements of the Δ^A_t vectors are captured by the last column of Table 2. Accordingly, for the year 2013,

$$\Delta^A_{2013} = \frac{1}{100}[0.24,\ 0.25,\ 0.42,\ 0.24,\ 0.35,\ 0,\ 0,\ 0,\ 0]'.$$

The vectors Δ^A_t for $t = 2014, 2015, 2016$ are obtained in this case by sequentially dropping off the first element of Δ^A_{t-1} and padding the additional empty space with a zero in order to preserve, again, the $9x1$ dimensions of this vector.

It is worth clarifying at this point a potential confusion created by the inclusion of the state vector S_t element $\ln \frac{ega_t}{y^{pr}_t} - \ln gy$ in the vector of observables Y_t as well. Strictly speaking, the variable directly observable in the data is ga_t, not the individual components identified in equation (10). However, as this equation makes apparent, in the absence of the temporary policy regime component pga_t, the stochastic component ega_t is equal to ga_t and therefore, observable as well. This equality holds, therefore, between 1997 and 2012, before the budget sequestration was triggered. When it breaks down in 2013, ega_t is no longer directly observable, but it can be inferred by adding to the observed ga_t the spending cuts that actually materialized in year t, that is, by performing the algebraic operation $ega_t = ga_t + sc_t$, where sc_t is extracted from the first element of the vector Δ^A_t.

Scrutinizing Existing Frisch Elasticity Estimates with the Budget Sequestration Evidence The preceding discussion built up the toolkit necessary to implement the "calibration stage" to scrutinize which of the considered existing Frisch elasticity values and associated state and parameter estimates best accounts for the sequestration evidence with the following sequence of steps:

1. The seven exogenous shocks realized between 2013 and 2016 were recovered, for each of the five Frisch elasticity values considered and associated parameter estimates, from the system of seven equations in seven unknown implied by (18):

$$\omega_{i,t} = C_i^{-1} Y_t - C_i^{-1} D_i S_{i,t-1} - C_i^{-1} \mathcal{B}_i \Delta_t^m,$$

   where $t = 2013, 2014, 2015, 2016$, $i = 1, 2, 3, 4, 5$ identifies the matrix or vector whose elements are a function of the parameter estimates associated with each the five Frisch elasticity values i considered and m denotes one of the three spending cuts scenarios assumed by economic agents. Recall that the vector of state variables $S_{i,2012}$ was obtained in the estimation stage.[12]

2. The Gaussian multivariate probability distribution of the seven observable macroeconomic variables in the vector Y_t induced by the state-space representation of the model was exploited to calculate the likelihood of the observations of those macroeconomic variables over the period 2013-2016, conditional on each Frisch elasticity value and spending cuts scenario considered. As indicated earlier, all distributional parameters relevant for this calculation were fixed at the values obtained in the estimation stage.

3. Finally, the ability of each Frisch elasticity value and associated parameter estimates to conform with the evidence for each scenario was ranked by the decreasing order of the corresponding value of the likelihood function.

[12] Given that C is a square matrix, this step is generally feasible, except in the rare occasion in which this matrix happens to be singular.

6 Findings

The results of the last step are documented in Table 6, whose column heading identify the Frisch elasticity value assumed in the estimation stage.

It turns out that the highest likelihood value for all the spending cuts scenarios is obtained with the state and parameter estimates indexed by the Frisch elasticity value of 0.5, the lowest among the five considered.

Thus, the independent validation of existing Frisch elasticity estimates with the responses of macroeconomic variables to the budget sequestration spending cuts is not particularly favorable to the high Frisch elasticity value of 3.0 that Prescott (2004) found to be consistent with cross country differences in hours worked and labor income tax rates.

To put this assessment in context, it should be pointed out that Prescott made that inference from comparing the different steady states of the economies he studied, implicitly assuming that economic agents perfectly anticipated the future path of fiscal policy. Such perfect foresight ability is explicitly captured in the present paper by the scenario in which economic agents are assumed to have foreseen the future spending cuts that would be actually implemented. As already noted, in this scenario the highest likelihood value is also attained by the statistically consistent set of parameter estimates indexed by a Frisch elasticity value of 0.5, the lowest in the list of existing estimates of that elasticity studied in the paper.

It doesn't seem fair, however, to assert that the findings of the paper definitely rule out the high value of 3.0 as an empirically plausible one for the aggregate Frisch elasticity. The differences in the values of the likelihood associated with each Frisch elasticity value and corresponding estimated states and parameters are not large enough to go that far.

On the other hand, the methodologies used by Prescott (2004) and Chetty *et al.* (2013) do not provide a well-defined criterion to rule out either the empirically plausibility of Frisch elasticity values different from those they inferred also from fiscal policy related evidence.

By contrast, the methodology proposed by the paper is capable of ranking the ability of

Table 6: Log likelihood of 2013-2016 observables

Year	**Combination of estimated parameters associated with Frisch elasticity value of:**														
	0.5			1.0			1.4			1.9			3.0		
	Spending cut scenario			Spending cut scenario			Spending cut scenario			Spending cut scenario			Spending cut scenario		
	Percent of statutory spending cuts anticipated to be implemented		Actually implemented 2013-2016	Percent of statutory spending cuts anticipated to be implemented		Actually implemented 2013-2016	Percent of statutory spending cuts anticipated to be implemented		Actually implemented 2013-2016	Percent of statutory spending cuts anticipated to be implemented		Actually implemented 2013-2016	Percent of statutory spending cuts anticipated to be implemented		Actually implemented 2013-2016
	100%	50%		100%	50%		100%	50%		100%	50%		100%	50%	
2013	***14.645***	***14.292***	***14.772***	14.633	14.281	14.764	14.623	14.271	14.756	14.609	14.259	14.745	14.582	14.235	14.723
2014	***13.934***	***13.581***	***13.943***	13.904	13.550	13.918	13.882	13.528	13.899	13.857	13.503	13.877	13.814	13.460	13.840
2015	***12.965***	***12.106***	***12.885***	12.900	12.032	12.834	12.854	11.982	12.796	12.806	11.931	12.756	12.730	11.849	12.690
2016	***7.259***	***6.645***	***7.102***	7.037	6.415	6.415	6.886	6.260	6.759	6.735	6.106	6.618	6.500	5.866	6.398
SUM	***48.804***	***46.623***	***48.703***	48.474	46.278	48.416	48.244	46.041	48.210	48.006	45.798	47.996	47.625	45.410	47.650

Notes: Statutory spending cuts are those scheduled as of the beginning of each year, as reported in Table 2. Figures in bold indicate year or period with the highest log likelihood value for the corresponding spending cuts scenario.

existing Frisch elasticity estimates to conform with the evidence from the budget sequestration with a metric that satisfies the standards of the estimation school of thought, the value of the likelihood function dictated by the probabilistic structure of the model economy, but calculated in a manner that meets the independent validation principle advocated by the calibration approach.

7 Concluding Remarks

The size of the aggregate intertemporal real wage labor supply elasticity hasn't been settled in the profession yet. The difficulties stem in part from the disagreements on how to measure the overall effect on that elasticity of the intensive and extensive margins of the labor supply decision.

What most microeconomic studies estimate is not the aggregate labor supply elasticity, but the *marginal-utility-of-wealth-held-constant* real wage elasticity of hours worked by already employed individuals, that is, the Frisch elasticity. The estimates of that elasticity are consistently low, to the point that there seems to be a wide consensus that its value is in the neighborhood of 0.5.

That doesn't mean, however, that the real wage labor supply elasticity in the aggregate, inclusive of the extensive margin, is that low. In fact, from the evidence provided by macroeconomic aggregates, Lucas and Rapping obtained an estimate for that parameter of 1.4, three times larger than the consensus estimate of the Frisch elasticity suggested by microeconomic studies.

Subsequently, the aggregation theory provided by Rogerson (1984, 1988) and Hansen (1985) justified the widespread adoption in the macroeconomic literature of utility functions in which a single parameter summarizes both the intensive and extensive margins of the labor supply. All the models that embrace that device need to do to properly understand a macroeconomic phenomena of interest is to adjust the magnitude of that aggregate Frisch elasticity parameter upward relative to the estimates of its microeconomic counterpart.

The Hansen-Rogerson aggregation theory didn't provide any guidance, however, on how large that adjustment should be. As a result, the issue is fiercely debated in the profession, because it matters for the answer to certain questions, such as the nature of the business cycle or the fraction of tax cuts that are self-financed by the responses they induce in the labor supply. As mentioned, the ability of TFP shocks to account almost exclusively for the business cycle phenomena hinges critically on a value of the aggregate Frisch elasticity in the order of 3.0.

The controversies are further complicated by the lack of agreement on the empirical methodology that should be used to infer the size of the aggregate Frisch elasticity from macroeconomic aggregates. The estimation school of thought insists that the value of that elasticity should be dictated by the probabilistic structure of the model economy meant to capture the essential features of the actual one under study. The calibration school of thought questions that view, on the grounds that setting the values of unknown parameters to those that best "fit the data" amounts to a tautology, that can only be avoided by pinning down them down with evidence different from that considered in addressing a particular macroeconomic question.

The present paper entered into that debate by examining the responses of macroeconomic variables to a U.S. fiscal policy regime change with quasi-experimental features, the budget sequestration spending cuts initiated in 2013, with a methodology that exploits a statistical metric that satisfies the standards of the estimation approach and meets, at the same time, the independent validation criterion endorsed by the calibration approach.

The considerations found in Ljungqvist and Sargent (2011) inspired the adoption of a Business Cycle Accounting approach for constructing a model economy designed to measure the value of the aggregate Frisch elasticity, as captured by a single parameter of the utility function, from the budget sequestration evidence. The resulting measuring device represents with exogenous stochastic processes frictions in labor and capital markets potentially present in the actual U.S. economy during the period under study.

The empirical methodology developed by the paper was guided by a chronology of events and previous findings suggesting that households and businesses didn't expect that the contingency that would trigger the spending cuts, prescribed in the 2011 Budget Control Act, would materialize until it actually did in 2013. The performance of macroeconomic variables during the years in which those cuts were in place can be interpreted, therefore, as capturing the effect of exposing households and businesses to the "controlled experiment" of suddenly, as if without previous warning, reducing the government absorption of private sector output for about a decade. The paper captures, however, in three different scenarios, the possibility that economic agents didn't expect that the spending cuts would materialize exactly in the terms prescribed by successive pieces of legislation.

The paper proceeded to exploit the state-state representation of the model economy with an estimation stage, designed to estimate the unknown state and parameters of the model economy consistent with five *existing* estimates of the Frisch elasticity, encompassing the wide range of those that have been proposed as empirically relevant in the micro and macroeconomic literature. As a way to respect the calibration point of view that "*parameters cannot be specific to the phenomenon being studied,*" as eloquently stated by Prescott (1986), the estimation was performed with data for the period 1977-2012, that is, excluding the observations under the influence of the budget sequestration spending cuts. For consistency with the previously given arguments, the optimal economic agents' decision rules, computed with a first order perturbation approach, didn't incorporate into this estimation stage the spending cuts policy regime change that took place in 2013.

The estimation stage delivered five sets of statistically consistent state and parameter estimates, each indexed by one the five existing aggregate Frisch elasticity estimates, in the 0.5-3.0 range inclusive of most of the values argued to be empirically relevant by a variety of studies, including those that have also examined fiscal policy related evidence. The calibration stage exploited those existing estimates to establish which of them are more consistent with the dynamics of macroeconomic variables during the budget sequestration period.

This was accomplished by first recomputing the economic agents' optimal decisions rules, this time incorporating the government spending cuts policy regime launched in 2013, as household and firms might have perceived it in three alternative plausible scenarios, for each of the five combination of parameter estimates, indexed by a corresponding assumed Frisch elasticity value, obtained in the estimation stage.

The final and critical step of calibration stage was to evaluate the likelihood of the observables implied by the model over the period 2013-2016, using to that effect the likelihood function induced by the new decision rules obtained as indicated above.

It turns out that in all the scenarios and for all the years between 2013 and 2016 for which the relevant observables were available at the time of this writing, the highest value of the likelihood was attained for the parameter estimates combination indexed by the aggregate Frisch elasticity value of 0.5, which was the lowest of those considered.

Moreover, the value of the likelihood is decreasing in that of the aggregate Frisch elasticity, a result not particularly favorable, then, to the high value of 3.0 for that elasticity that Prescott (2004) inferred also from fiscal policy related evidence. As pointed out by Ríos-Rull *et al.* (2012), that inference was obtained under such specific assumptions that it is legitimate to question its generality. That paper and the findings of this one are not the first to add to those doubts. A good number of studies, such as those by Heathcote, Storesletten, and Violante (2010, 2014) and Fiorito and Zanella (2012) suggest that the upper bound for that elasticity is half the size of that obtained by Prescott, and perhaps not far from the value of 1.4 estimated by Lucas and Rapping that sparked the heated debate on the magnitude of the aggregate labor supply elasticity.

In any case, given that the differences in the values of the likelihood implied by the Frisch elasticity values examined in this paper are not significantly large, it seems fairer to assert that the budget sequestration evidence favors more the low than the high values of that elasticity invoked as empirically relevant by the participants of that debate.

In closing, it is important to emphasize, once more, that the findings reported in this paper were obtained within the "single parameter" aggregate Frisch elasticity paradigm inspired by the Hansen-Rogerson aggregation theory. As mentioned before, Ljungqvist and Sargent (2011) have questioned the wisdom of using that paradigm to obtain reliable estimates of the aggregate intertemporal real wage labor supply elasticity. They have advanced the hypothesis that the alternative "time averaging" aggregation theory, with more solid microfoundations, is better suited to the task. Empirical implementation of that theory, however, involves dealing with the complication that the intensive and extensive margins of the labor supply decision must be treated separately. It remains to be seen if the research agenda proposed by those authors will deliver estimates of the aggregate labor supply elasticity in the neighborhood of 3.0 required to validate the view that TFP shocks account for the bulk of the business cycle.

APPENDIX A

Data Sources

- For national accounts variables: Bureau of Economic Analysis, National Income and Product Accounts as measured by the new methodology adopted in 2013.
- For the capital stock: Bureau of Economic Analysis, "Fixed Assets and Consumer Durable Goods."
- For hours worked in the private and public sectors: Bureau of Economic Analysis, Income and Employment by Industry, Hours Worked by Full-Time and Part-Time Employees.
- For civilian population, military personnel, persons at work, aggregate average hours worked: Cociuba, Prescott, and Ueberfeldt (2018), Department of Defense, and Household Survey from Bureau of Labor Statistics.

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