News Shocks and their Role in Empirical Economics

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Abstract

This thesis contributes to the existing theoretical and empirical literature on the impact of anticipated shocks, called “news shocks”, concerning individual behavior and economic fluctuations. It consists of three studies, of which two are published in peer-reviewed journals.

The first study, “News Shocks, Nonseparable Preferences, and Optimal Monetary Policy”, has been published in the *Journal of Macroeconomics* and provides a novel approach to explore news shocks and their implications for monetary policy. It extends and modifies the canonical New Keynesian model by embedding a nonseparable household preference structure. The results show that news shocks cause larger economic fluctuations than unanticipated shocks of the same form and thus behave in a welfare-reducing manner. Unrestricted monetary policy under commitment constitutes the optimal choice for policymakers.

The second study, “The Olympic Games as a News Shock: Macroeconomic Implications”, is a collaboration with Wolfgang Maennig and Felix Richter and has been published in the *Journal of Sports Economics*. This empirical study investigates the economic impact of the Olympic Games on host regions in the short and long term by applying methodology from the news shocks literature. The analysis also incorporates an appropriate number of leads and lags to capture the potential economic effects of the mega event represented by the Olympics. Furthermore, the analysis includes determinants of economic growth and implements various empirical models, such as propensity score matching and entropy balancing, and utilizes data from the World Bank and Penn World Data. The results do not show any significant economic effects caused by the Olympic Games.

The third study, “Prevention Effect of News Shocks in Anti-Doping Policies”, is a collaboration with Wolfgang Maennig. It develops a dynamic general equilibrium news-driven model of delinquency and analyzes the expected doping behavior of athletes in elite sports. We modify the growth model proposed by Kydland and Prescott (1982) by incorporating a capital formation process following Sickles and Williams (2008) used in the field of behavioral economics. We further incorporate a general Cobb-Douglas-type production function following Zech (1981) used in sports economics. The results show that the anticipation of policy changes reduces drug abuse among athletes.

Zusammenfassung

Die Dissertation analysiert den Einfluss von antizipierten Schocks, sogenannte Nachrichtenschocks oder News-Schocks, auf das individuelle Verhalten von Wirtschaftssubjekten sowie auf das Konjunkturgeschehen. Sie besteht aus drei Aufsätzen, von denen zwei in begutachteten wissenschaftlichen Zeitschriften publiziert sind.

Der erste Aufsatz „News Shocks, Nonseparable Preferences, and Optimal Monetary Policy“ ist im *Journal of Macroeconomics* veröffentlicht und entwickelt einen neuartigen Modellansatz, um Nachrichtenschocks und die damit einhergehenden Konsequenzen für die (optimale) Geldpolitik zu eruieren. Hierfür wird das traditionelle Neukeynesianische Modell um eine additiv nicht-separable intertemporale Nutzenfunktion modifiziert. Die Ergebnisse zeigen, dass antizipierte Schocks zu höheren konjunkturellen Schwankungen führen und somit wohlfahrtsreduzierender wirken als herkömmliche (d. h. nicht antizipierte) Schocks. Zudem erweist sich die unrestringierte Geldpolitik unter Commitment (d. h. eine glaubwürdige Selbstverpflichtung der Zentralbank auf die Regelbindung) als optimale geldpolitische Strategie der Zentralbank, wenn antizipierte Kostenschocks vorliegen.

Der zweite Aufsatz „The Olympic Games as a News Shock: Macroeconomic Implications“, entstand in Zusammenarbeit mit Wolfgang Maennig und Felix Richter und ist im *Journal of Sports Economics* publiziert. Unter Anwendung der News-Schock-Theorie werden die kurz- und langfristigen ökonomischen Auswirkungen der Olympischen Spiele auf die Bewerber und Gastgeber beleuchtet. Es werden Daten der Weltbank und des Penn World Table mit Hilfe unterschiedlicher statistischer Verfahren (z. B. Differenz-von-Differenzen-Ansatz, Entropy-Balancing und Propensity-Score Matching) analysiert. Die Ergebnisse zeigen keine signifikanten wirtschaftliche Effekte der Olympischen Spiele.

Der dritte Aufsatz „Prevention Effect of News Shocks in Anti-Doping Policies“ ist in Zusammenarbeit mit Wolfgang Maennig entstanden. Entwickelt wird ein dynamisches Kriminalitätsmodell, um das erwartete Dopingverhalten von Spitzensportlern zu untersuchen. Hierfür werden zwei wesentliche Bestandteile des traditionellen Wachstumsmodells von Kydland und Prescott (1982) modifiziert. Zum einen wird der herkömmliche Prozess der Kapitalbildung durch den von Sickles und Williams (2008) aus der Verhaltensökonomik bekannten Kapitalbildungsprozess ersetzt. Zum anderen wird die von Zech (1981) in der Sportökonomik angewandte Cobb-Douglas-typische Produktionsfunktion integriert. Die Analyseergebnisse zeigen, dass bereits die Antizipation von Änderungen in der Anti-Doping-Politik zu einer reduzierten Einnahme von leistungssteigernden Medikamenten von Spitzensportlern führen kann.

Selbstdeklaration und Publikationen

Konzeption/Planung: Formulierung des grundlegenden wissenschaftlichen Problems, basierend auf bisher unbeantworteten theoretischen Fragestellungen inklusive der Zusammenfassung der generellen Fragen, die anhand von Analysen oder Experimenten/Untersuchungen beantwortbar sind. Planung der Experimente/Analysen und Formulierung der methodischen Vorgehensweise, inklusive Wahl der Methode und unabhängige methodologische Entwicklung.

Durchführung: Grad der Einbindung in die konkreten Untersuchungen bzw. Analysen.

Manuskripterstellung: Präsentation, Interpretation und Diskussion der erzielten Ergebnisse in Form eines wissenschaftlichen Artikels.

Die Einschätzung des geleisteten Anteils erfolgt mittels Punkteinschätzung von 1 – 100 %.

Kapitel 2

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Kapitel 3

Koautoren: Wolfgang Maennig, Felix Richter.

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Kapitel 4

Koautor: Wolfgang Maennig.

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Für meine Eltern und Mathias

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List of Abbreviations

AIC	Akaike information criterion
ARIMA	Autoregressive integrated moving average
BP	Brückner and Pappa
CPI	Consumer price index
DE	Doping efficiency
DH	Doping harm
DSGE	Dynamic stochastic general equilibrium
FE	Fixed effects
GDP	Gross domestic product
GHH	Greenwood et al. (1988)
JR	Jaimovich and Rebelo
KPR	King et al. (1988)
NADA	National Anti-Doping Agency
NK	New Keynesian
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary least squares
OSR	Optimal simple rules
PES	Performance-enhancing substance
PPP	Purchasing power parity
PSM	Propensity score matching
PWT	Penn World Table
RBC	Real business cycle
SD	Standard deviation
SUC	Athletic success
TOT	Terms of trade

VAR	Vector autoregressive
WADA	World Anti-Doping Agency

1 Introduction

It can be said that each of us makes a plethora of minor decisions every day, from choosing coffee or tea for breakfast, to putting on blue or the black trousers, to driving or biking to work. At the same time, we must also make decisions with more far-reaching consequences such as deciding between academic studies or apprenticeships, accepting or declining a job offer, renting or buying a house, or having children—just to name a few. According the Rational Expectations Theory—initiated by John F. Muth in the early 1960s—our individual decision making and thus our behavior is substantially dependent on four main factors: human rationality, available information, past experiences, and expectations. Expectations are defined as personal beliefs that something is going to happen or will be the case in the future. The theory also suggests that optimistic expectations and thus people's current speculations about future economic developments may positively affect the actual outcome (Muth, 1961), with the reverse being true for negative expectations. In other words, the expectation—or anticipation—of a change may actually help bring about that change. Because people continuously rethink and adjust their beliefs and expectations regarding future events, available information (e.g., from news, the media, market sentiments, and public signals from policymakers) are likely to be of great relevance.

After the seminal works of Beaudry and Portier (2004) and Jaimovich and Rebelo (2009), economists seem to agree that economic fluctuations may be driven by anticipations, especially by anticipated shocks. Anticipated shocks—also called news shocks—do not constitute an exogenous change in current macroeconomic fundamentals. However, these shocks may affect the current market expectations of their agents. In other words, agents receive a signal today regarding economic developments tomorrow, such as higher productivity growth, and immediately adjust their contemporaneous investment, consumption, and work decisions (Fève et al., 2009; Jaimovich and Rebelo, 2009). Consequently, the announcement of forthcoming shocks may significantly affect the dynamic adjustment process by changing the volatility and persistence of endogenous economic variables (Barsky and Sims, 2011; Fève et al., 2009; Jaimovich and Rebelo, 2009).

A large body of literature has recently been contributed to the debate on the effects and consequences of news shocks. Beaudry and Portier (2014) offers an excellent literature review. Most studies primarily focus on the impact of news on business cycle fluctuations (Jaimovich and Rebelo, 2009; Beaudry and Portier, 2006; Schmitt-Grohé and Uribe, 2012; Fujiwara et al., 2011; Christiano et al., 2014). Mertens and Ravn (2012), Leeper et al. (2008), and Gambetti

(2012) focus on fiscal news shocks—including government spending and changes in tax policy. Ben Zeev and Pappa (2017) investigate U.S. defense spending news shocks. Brückner und Pappa (2015) implement the news shock theory in the field of sports economics.

This thesis contributes to the growing theoretical and empirical literature in the field of news shocks. It is based on three independent articles, which can be read separately, and of which two are published.

1.1 Outline

The remainder of this thesis is organized as follows. Chapter 2 is based on the article "News Shocks, Nonseparable Preferences, and Optimal Monetary Policy", and has been published in the *Journal of Macroeconomics* 49, pp. 237-246 in 2016. It contributes to the literature in three aspects: first, it presents a new approach to investigate the implications of news shocks on economic activities. Second, it is one of the few studies to analyze welfare aspects of anticipations. Third, it investigates how optimal monetary policy should be conducted in the presence of news shocks.

The article develops a novel model framework and explores the impact of anticipated cost-push shocks on business cycles. The basic structure of the model follows the canonical closed and cashless New Keynesian model proposed by Galí (2008), with price stickiness à la Calvo (1983), and no investment or capital. To that basis, the new model adds a nonseparable Jaimovich/Rebelo (2009)-type utility function. This utility specification includes a backward-looking element, which makes preferences nonseparable over consumption and leisure/labor supply. In addition, the model incorporates a monetary authority, which minimizes a quadratic loss function in inflation and output as a measure of welfare.

The main results are as follows: (1) Compared to cost-push shocks which are unanticipated, anticipated shocks amplify the volatility of endogenous variables (such as output, price level, and hours worked) and thus behave in a welfare-reducing manner. (2) An investigation of optimal simple interest rules shows that the lowest welfare loss correlates with a central bank's monetary policy in which interest rate rules respond not only to contemporaneous but also to expected values of inflation and output.

Finally, although one might expect social welfare gains due to agents' improved perceptions of economic needs due to a higher availability of economic data, the results of this study indicate the opposite. Based on this result, it might not be rational for a central bank to announce monetary policy responses to economic shocks in advance.

Chapter 3 is based on the article entitled "The Olympic Games as a News Shock: Macroeconomic Implications", which is joint work with Wolfgang Maennig and Felix Richter and has been published in the *Journal of Sports Economics* 19(6), pp. 884-906 in 2018. Applying and combining techniques and insights from various theories, this chapter contributes to the existing literature on economic growth, business cycles, sports economics, and news shocks.

The study applies news theory methodology and estimates the economic effects of the Olympic Games on host regions in the short and long term. The result of awarding the Olympic Games to a given city or nation—seven years in advance—and the announcement of a city or nation's Olympic bid—nine years in advance—can be considered as news shocks that have effects on agents' market expectations.

The empirical strategy implements various structural models and departs from previous studies in many ways. By expanding the time span under investigation and applying an appropriate number of leads and lags to capture the potential economic anticipation and realization effects of the Olympics, we introduce news theory techniques. To ensure an all-encompassing analysis, we include well-established standard determinants of economic growth, such as investment growth, government spending growth, human capital and so on. To avoid sample selection bias, we employ propensity score matching to identify countries that are structurally similar to the bidding and hosting countries but are not bidders themselves. In another specification, we apply entropy balancing to account for the structural differences between the treatment and control group. In line with previous findings reported in the literature, we do not find significant news shocks or realization effects regarding the Olympic Games.

Although there might be advantageous reasons to bid for the Olympic Games, the results serve as a warning that expectations regarding income effects should not be part of rational motivations. Thus, policy makers should be skeptical that organizing the Olympic Games is a particularly efficient approach to fiscal spending, inducing multiplier effects of incomparable size.

Chapter 4 is based on the paper "Prevention Effect of News Shocks in Anti-Doping Policies" which is joint work with Wolfgang Maennig. The chapter contributes to the debate on anti-doping policies and adds to the research on news shocks, sports economics, health economics, and behavioral economics.

We develop a dynamic general equilibrium model of delinquency to analyze the expected doping behavior in elite sports in the presence of two different types of news shocks: (1) the announcement of improved drug testing technological opportunities and (2) the announcement of future increases in financial sanctions in case of detected anti-doping rule violations.

Our model framework is based on the growth model initiated by Kydland and Prescott (1982) and news-driven models suggested by Beaudry and Portier (2004) and Jaimovich and Rebelo (2009). We adopt and incorporate a capital formation process used in the fields of behavioral economics as proposed by Sickles and Williams (2008) in order to separate an athlete's stock into a "fairly" accumulated sporting capital (e.g., training effort) component and a sporting capital component accumulated through the use of prohibited performance-enhancing substances. In addition, we incorporate a general form of the Cobb-Douglas-type sporting production function following Zech (1981) used in the fields of sports economics in order to measure the performance of a managing sporting institution (e.g., federation, club, or team manager) that acts similarly to an enterprise.

We find that the anticipation of policy changes affects the behavior of potentially delinquent athletes. In both scenarios, our simulations show an immediate drop in aggregate expected delinquent behavior, well before the increased probability of detection or higher sanctions take effect. We conclude that announced changes in crime prevention may increase the benefits of the implementation of "real" changes by prolonging the effects in the presence of the announcement, thus enhancing the efficiency of the policy going into effect.

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2 News Shocks, Nonseparable Preferences, and Optimal Monetary Policy

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Abstract

Extending and modifying the canonical New Keynesian (NK) model by embedding a nonseparable Jaimovich/Rebelo (2009)-type utility function, this study provides a novel approach to examine the impact of anticipated shocks, called "news shocks", on business cycles. It can be shown that news shocks cause larger economic fluctuations than unanticipated shocks of the same form and thus behave in a welfare-reducing manner. Given this, the article explores how (optimal) monetary policy should be conducted. In line with earlier studies, the investigation of several Taylor-type interest rate rules shows that the lowest welfare losses can be achieved based on rules that respond to both contemporaneous and expected future macroeconomic conditions.

JEL classification: E32, E52

Keywords: Anticipated shock, welfare, business cycle, monetary policy, Taylor rule

2.1 Introduction

The nature of business cycle activities is a long-standing debate among macroeconomists. In recent years, there has been a renewed interest in a deep-seated idea tracing back to Pigou (1927)—that cyclical fluctuations cannot be explained solely by unpredictable random shocks that immediately cause reactions in current macroeconomic fundamentals, such as aggregate productivity. Even households' expectations about future economic development represent a key determinant.[1]

In this context, there is a growing body of literature that discusses the relevance and impact of anticipated shocks, called "news shocks". News shocks contain useful information for predicting future fundamentals but do not cause changes in current fundamentals; thus, these shocks only affect agents' expectations.

Beaudry and Portier (2006) use a structural vector autoregressive (VAR) approach to evaluate the role of news shocks. They find that news about total factor productivity is responsible for about 50% of the variance in consumption, output, and hours worked. Schmitt-Grohé and Uribe (2012) use an estimated Real Business Cycle (RBC) model to show that news shocks account for over 40% of output fluctuations. In fact, most studies emphasize the destabilizing effects of anticipated shocks as a quantitatively important source of economic fluctuations (see, for instance, Beaudry and Lucke, 2010; Davis, 2007; Fève et al., 2009; Leeper et al., 2008; Winkler and Wohltmann, 2012). In contrast, comparatively few papers—like those of Kahn and Tsoukalas (2012) and Forni et al. (2014)—conclude that news shocks play a relatively minor role in explaining business cycle activities.[2] In particular, Kahn and Tsoukalas (2012) document that news shocks explain less than 15% of output fluctuations. In a recent paper, Offick and Wohltmann (2016) bridge the gap by focussing on both fully anticipated and partially anticipated monetary policy shocks. Using a dynamic Dornbusch-type model, they highlight that partial anticipation of monetary policy shocks may lead to lower macroeconomic activity than fully anticipated shocks of the same form.

This article contributes to the ongoing debate surrounding the relevance of anticipated shocks on economic activities by examining their welfare implications for an economy. In this way, the article is linked to Jaimovich and Rebelo (JR) (2009), who show that an increase in the availability of information leads to a reduction in economic fluctuations. For this purpose, they

[1] See, for instance, Beaudry and Portier (2014), who provide a comprehensive literature review on the hypothesis of news-driven business cycles.
[2] Other studies that provide proof that news about the future represents a relatively irrelevant source of business cycle fluctuation are, for instance, Barsky and Sims (2011), Barsky et al. (2015), and Fujiwara et al. (2011).

propose a RBC framework that is able to generate pro-cyclical economic development in response to good news—in the form of anticipated productivity shocks—about the future. Applying the methods suggested by JR (2009) by embedding their nonseparable preference structure in the baseline New Keynesian (NK) model, this article provides a novel model framework.

Second, the article is closely related to Wohltmann and Winkler (2009)—one of the few studies examining both welfare aspects and (optimal) monetary policy in case of anticipated shocks in the baseline NK model.[3] In contrast to Wohltmann and Winkler (2009), this article investigates the welfare dynamics of news shocks as well as their (optimal) monetary policy implications given the above-mentioned novel dynamic stochastic general equilibrium (DSGE) model structure, including a nonseparable JR (2009)-type utility function.

The main results are as follows: (1) Compared to unanticipated cost-push shocks, anticipated cost-push shocks amplify the volatility of endogenous variables (such as output, price level, and hours worked) and thus behave in a welfare-reducing manner. (2) An investigation of optimal simple interest rules shows that the lowest welfare loss correlates with a central bank's monetary policy in which interest rate rules respond not only to contemporaneous but also to expected values of inflation and output.

The article is organized as follows: Section 2.2 details the DSGE model framework. Section 2.3 investigates macroeconomic volatility effects and monetary policy implications when an economy is faced with (un)anticipated cost-push shocks. Section 2.4 concludes.

2.2 Theoretical Framework

A rational expectations NK model for a cashless economy without capital, as proposed by Galí (2008), is assumed.[4] However, the conventional additively separable utility function of the canonical NK model is replaced by a preference structure that was first proposed by Greenwood et al. (1988) and then generalized by JR (2009). Therefore, the utility U follows the general structure $U(X) = \frac{X^{1-\sigma}-1}{1-\sigma}$ with $X = C - \psi N^{\theta} S$. More precisely, the period utility function U_t of an infinitely-lived representative household is given by the following:

$$U_t = E_t \sum_{k=0}^{\infty} \beta^k \, U_{t+k}(C_{t+k}, N_{t+k}, S_{t+k}) = E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{(X_{t+k})^{1-\sigma} - 1}{1-\sigma} \right] \tag{2-1}$$

[3] Further studies that address the question of how monetary policy should be conducted in the presence of anticipated shocks include Kapinos (2011), Best and Kapinos (2016), and Winkler and Wohltmann (2011).
[4] For a detailed derivation of the basic NK model, see Galí (2008) and others.

with

$$X_{t+k} = C_{t+k} - \psi N_{t+k}^{\theta} S_{t+k} \tag{2-2}$$

and

$$S_{t+k} = C_{t+k}^{\gamma} S_{t+k-1}^{1-\gamma} \tag{2-3}$$

where $U_{t+k}(k = 0,1,2, \dots), 0 < \beta < 1, \psi > 0, 0 < \gamma < 1, \theta > 0$, and $\sigma > 0$. E_t is the expectation operator, which is conditional upon information available up to period t. β is the discount factor. S_t, the geometric average of current and past consumption levels, represents a backward-looking element and implicates the nonseparability in preferences over consumption C_t and labor service N_t. $\frac{1}{\sigma}$ and θ represent the intertemporal elasticity of consumption and labor supply, respectively. A crucial element in the utility function is parameter $\gamma \in (0,1)$, as this parameter stands for the household's substitution behavior between consumption and hours worked (or leisure) as a consequence of an economic shock. If, for example, a favorable productivity shock hits an economy, households increase both consumption and leisure. The latter requires a reduction in labor supply, which causes a decline in output. Controlling for the household's adjustment process—or, in other words, the strength of the wealth effect on labor supply—suggests the possibility of generating procyclical comovements of endogenous variables in the presence of unanticipated shocks as well as news shocks of the same form. Adopting the preference specification according to Greenwood et al. (1988) called GHH preferences by setting $\gamma = 0$ completely eliminates the wealth effect and thus avoids a downward shift in labor supply (due to anticipated positive technology shocks). Therefore, labor supply depends only on the current real wage. Consequently, high values of parameter γ imply a high wealth elasticity of labor supply. As $\gamma = 1$, equation (2-1) follows a preference structure according to King et al. (1988) (KPR preferences henceforth), and the wealth effect is not restricted.

Furthermore, households maximize their utility given by equation (2-1) subject to equation (2-3) and the period budget constraint (expressed in real terms):

$$C_{t+k} = \frac{-B_{t+k}}{P_{t+k}} + \frac{W_{t+k}}{P_{t+k}} N_{t+k} + (1 + i_{t+k-1}) \frac{B_{t+k-1}}{P_{t+k}} + \Pi_{t+k} - \frac{T_{t+k}}{P_{t+k}} \tag{2-4}$$

The Lagrangian L_t is then given by the following:

$$L_t = E_t \sum_{k=0}^{\infty} \beta^k \left\{ \frac{(X_{t+k})^{1-\sigma} - 1}{1-\sigma} \right.$$
$$+ \lambda_{1,t+k} \left(C_{t+k} + \frac{B_{t+k}}{P_{t+k}} - \frac{W_{t+k}}{P_{t+k}} N_{t+k} - (1 + i_{t+k-1}) \frac{B_{t+k-1}}{P_{t+k}} \right. \tag{2-5}$$
$$\left. \left. - \Pi_{t+k} + \frac{T_{t+k}}{P_{t+k}} \right) + \lambda_{2,t+k} \left(S_{t+k} - C_{t+k}^{\gamma} S_{t+k-1}^{1-\gamma} \right) \right\}$$

where $\lambda_{1,t+k}$ and $\lambda_{2,t+k}$ are the Lagrangian multipliers on the corresponding constraints. The notation is as follows: B_t denotes riskless nominal government bonds, i_t is the nominal interest rate, P_t is the price level, T_t represents nominal taxes or dividends, W_t is the nominal wage, and Π_t denotes real profits. The remaining variables are defined as mentioned above.

The first-order conditions for an economy's planning problem are as follows:

$$\frac{\partial L_t}{\partial C_t} = X_t^{-\sigma} + \lambda_{1,t} - \lambda_{2,t} \gamma C_t^{\gamma-1} S_{t-1}^{1-\gamma} = 0 \tag{2-6}$$

$$\frac{\partial L_t}{\partial N_t} = -\lambda_{1,t} \frac{W_t}{P_t} - X_t^{-\sigma} N_t^{\theta-1} \psi S_t \theta = 0 \tag{2-7}$$

$$\frac{\partial L_t}{\partial S_t} = \lambda_{2,t} - \psi N_t^{\theta} X_t^{-\sigma} + \beta(\gamma - 1) E_t C_{t+1}^{\gamma} E_t \lambda_{2,t+1} S_t^{-\gamma} = 0 \tag{2-8}$$

$$\frac{\partial L_t}{\partial B_t} = \lambda_{1,t} \frac{1}{P_t} - \beta E_t \lambda_{1,t+1} (1 + i_t) E_t \left(\frac{1}{P_{t+1}} \right) = 0 \tag{2-9}$$

The combination of equations (2-6), (2-7), and (2-9) yields the non-linear forward-looking dynamic IS curve:

$$\frac{\lambda_{2,t}}{E_t \lambda_{2,t+1}} \frac{\gamma C_t^{\gamma-1} S_{t-1}^{1-\gamma} + \lambda_{1,t} \frac{W_t N_t^{1-\theta}}{P_t \psi S_t \theta}}{\gamma E_t C_{t+1}^{\gamma-1} S_t^{1-\gamma} + \lambda_{1,t} \frac{E_t W_{t+1} E_t N_{t+1}^{1-\theta}}{E_t P_{t+1} \psi E_t S_{t+1} \theta}} = \beta \frac{(1 + i_t)}{E_t \pi_{t+1}} \tag{2-10}$$

Moreover, the model comprises the log-linearized purely forward-looking inflation equation given by the following:

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\omega)(1-\omega\beta)}{\omega} \widehat{mc}_t + \hat{e}_t \tag{2-11}$$

where $(0 < \beta < 1)$.[5] $\hat{\pi}_t$ represents inflation, whereas $E_t\hat{\pi}_{t+1}$ is the next period's expected inflation rate. For numerical simulations a price setting structure according to Calvo (1983), i.e., that each period, only a random fraction $(1-\omega)$ of firms are able to optimize their prices, is assumed. Parameter ω denotes the degree of price rigidity, $\widehat{mc}_t$ represents real marginal costs, and $\hat{e}_t$ is the (un)anticipated temporary cost-push shock.

Finally, the production function logarithmized is given by the simplest form:

$$\hat{y}_t = \hat{n}_t + \hat{a}_t \tag{2-12}$$

where $\hat{a}_t = \rho\hat{a}_{t-1} + \varepsilon^a_{t-q}$ denotes a temporary technology news shock.[6] The letter q refers to the anticipation horizon or lead time of a shock. Appendix A provides a complete summary of the log-linearized model.

2.3 Welfare Analysis and Monetary Policy

In the following analyses, business cycle fluctuations in the model are driven by temporary (un)anticipated cost-push shocks $\hat{e}_t$ (i.e., price mark-up shocks). Therefore, $\hat{e}_t$ follows an exogenous process and takes the log-linearized form $\hat{e}_t = \rho\hat{e}_{t-1} + \varepsilon^e_{t-q}$, where $\rho \in [0,1)$ denotes persistence and ε^e_{t-q} denotes an i.i.d. random economic disturbance with a zero mean, which is announced q quarters before it materializes. Note, for $q = 3$, the cost shock is signalized three quarters ahead, whereas for $q = 0$, the disturbance is unpredictable by agents. The monetary authority adopts an inflation-targeting regime (i.e., price stability is the main goal of the monetary policy) and minimizes the intertemporal quadratic loss function:

$$J_t = E_t \sum_{k=0}^{\infty} \beta^k (\alpha_1 \pi^2_{t+k} + \alpha_2 y^2_{t+k}) \tag{2-13}$$

Equation (2-13) is given ad hoc and does not follow from a second-order approximation of equation (2-1).[7] From a welfare point of view, equation (2-13) implies that the stabilization of inflation and output at their steady state values is desirable.[8]

[5] Notice that variables with hats represent percentage deviation from a steady state.
[6] The presented model generates a cyclical upturn in response to favorable (un)anticipated technology shocks. Similar to Smets and Wouters (2003), technology shocks have an ambiguous effect on the welfare measured by the model's output and inflation variances. However, the model gives unambiguous results for cost shocks.
[7] Note that the assumed central bank's loss function (2-13) cannot be deduced from the household's utility maximization under nonseparable preferences.
[8] The stated goal of monetary policy concerning output is output stabilization at its natural level, which may fluctuate in response to real shocks.

Unless otherwise stated, in numerical simulations of this study, the parameterization closely follows JR (2009): $\alpha_1 = 1,\ \alpha_2 = 0.5, \beta = 0.99, \rho = 0.8, \sigma = 1, \delta_y = 0.5, \delta_\pi = 1.5$, and $\omega = 0.75$. $\gamma = 0.01$ and $\theta = 1.16$ follow Schmitt-Grohé and Uribe (2012), who provide estimates for both parameters.[9]

2.3.1 Unrestricted Monetary Policy

Among others, Walsh (2010) supplies evidence that unrestricted policy under commitment constitutes the optimal monetary response when cost-push shocks enter an economy; this study indicates the same.

To investigate the implications of (un)anticipated cost shocks in the underlying monetary policy regime, Table 2-1 displays the reaction of the output variance ϕ_y, inflation variance ϕ_π, and welfare loss J_t based on GHH and KPR preferences and under low $(\omega = 0.25)$ and high $(\omega = 0.75)$ price rigidity, respectively. In order to check the robustness of the results, an extended version of Table 2-1 (Table 2-3) can be found in Appendix B.[10] Besides further levels of price stickiness, Table 2-3 also reports the upper endpoint q^{max} of a lead time interval $[0, q^{max}]$. The starting point of the interval, 0, states the unpredictability of shocks ($q = 0$). The upper endpoint of the interval, q^{max}, states the respective maximum anticipation horizon up to which the volatility of a variable is monotonically increasing in q. In other words, within the interval $[0, q^{max}]$, the volatility of the considered variable increases monotonically in the anticipation horizon q. However, beyond the stated upper endpoint q^{max} and outside the interval, respectively, the volatility induced by news shocks is still larger than (or at least equal to) the volatility induced by unexpected shocks. However, it is not necessarily a non-decrease in q. Note that if no upper endpoint q^{max} exists, i.e., the volatility is non-decreasing in q over all investigated anticipation horizons, an infinity sign is used in the table to indicate this.[11]

Based on Table 2-1 and Table 2-3 in Appendix B, the main results can be summarized in the following four propositions.

[9] Numerical simulations were solved with the software platform Dynare, which was developed by Adjemian et al. (2011).

[10] Furthermore, in addition to Table 2-3 in Appendix B, a second robustness check of the findings summarized in Propositions 1–4 can be found in Table 2-4 in Appendix B. Table 2-4 documents the results for the special case of no time discounting $(\beta = 1)$ in the intertemporal loss function. The table provides proof that even in this special case, results similar to those achieved in the case of $\beta = 0.99$ remain true.

[11] To conduct extensive robustness checks, various in the literature often assumed scenarios of price rigidity have been analyzed. For brevity, Table 2-3 and Table 2-4 in Appendix B are limited to show only five different levels of nominal price rigidity: $\omega = 0.25, \omega = 0.40, \omega = 0.55, \omega = 0.66$, and $\omega = 0.75$ for up to twelve quarters, i.e., three years. More results are available upon request.

Table 2-1 Variances and Welfare Losses with Unrestricted Monetary Policy under Commitment.

		$\omega = 0.25$			$\omega = 0.75$		
		$q = 0$	$q = 3$	$q = 8$	$q = 0$	$q = 3$	$q = 8$
$\gamma = 0.001$	ϕ_y	0.9868	1.4079	1.4470	1.1443	2.8028	6.5528
	ϕ_π	0.2308	0.1769	0.1635	5.2483	10.1803	16.3479
	J_t	0.7242	0.8809	0.8870	5.8205	11.5818	19.6243
$\gamma = 0.01$	ϕ_y	0.8929	1.2288	1.1569	1.1005	2.6218	5.6675
	ϕ_π	0.2886	0.2395	0.2755	4.4081	8.1460	11.7426
	J_t	0.7350	0.8539	0.8540	4.9583	9.4569	14.5764
$\gamma = 1$	ϕ_y	0.0135	0.0135	0.0135	1.6858	2.9968	3.6728
	ϕ_π	0.0001	0.0001	0.0001	0.7450	0.7912	0.6478
	J_t	0.0068	0.0068	0.0068	1.5878	2.2896	2.4842

Notes: The table reports the relative output variance ϕ_y, relative variance of inflation ϕ_π, and welfare loss J_t in response to a temporary (un)anticipated cost-push shock in the case of low ($\omega = 0.25$) and high ($\omega = 0.75$) price rigidity. The letter q refers to the anticipation horizon. Parameterizations $\gamma = 0.001$ and $\gamma = 0.01$, as estimated by Schmitt-Grohé and Uribe (2012), denote GHH preferences, whereas $\gamma = 1$ denotes KPR preferences.

Proposition 1. *The output volatility (measured by the output variance ϕ_y) induced by unanticipated cost-push shocks is less than the volatility due to anticipated shocks of equal magnitude. This finding is irrespective of the length of the anticipation horizon q, the degree of price stickiness ω, and parameter γ:*

$$\phi_{y,q=0} < \phi_{y,q>0} \text{ for all } q > 0,$$

$$\text{all } \omega > 0, \text{ and } \gamma \in (0,1).$$

In regard to Proposition 1, the analysis shows that even though the output volatility monotonically increases with an increasing anticipation horizon q and increasing degree of price stickiness ω only in the case of $\gamma = 1$, it is true that the output volatility due to an unanticipated cost-push shock is always lower than the corresponding output volatility induced by an announced shock.

If γ is close to zero, two facts are notable: first, the output volatility is not monotonic in the degree of price rigidity. Table 2-3 in Appendix B shows that the output volatility first rises but then falls with an increasing degree of price rigidity. Second, the output volatility is monotonically increasing in the anticipation horizon q at least in a particular time interval $[0, q^{max}]$.

The upper endpoints q^{max} of the interval depend on the exogenously given degree of nominal rigidity ω. More precisely, the lower the level of rigidity, the higher the upper endpoint of the anticipation horizon. Appendix B Table 2-3 provides the values of q^{max}. Take, for instance, $\gamma = 0.001$. The table shows that in the context of low price indexation (e.g., $\omega = 0.25$), the

upper endpoint q^{max} is seven. By contrast, assuming a high price indexation (e.g., $\omega = 0.75$), the investigation does not reveal any upper endpoint; this is denoted in the table with an infinity symbol.

However, there is no need to attach too much importance in case of the existence of an upper endpoint q^{max} for two main reasons. First, as already mentioned above, even beyond q^{max}, news shocks induce higher or equal output volatility than unexpected shocks and thus do not cause welfare gains. Second, for empirically realistic and in economic studies often referred levels of price rigidity (e.g., $\omega = 0.75$), q^{max} is very large. From an economic point of view, the announcement of a future rise in costs more than two years in advance seems to be unreasonable.

Proposition 2. *If $\gamma \to 0$ and the degree of nominal rigidity ω is sufficiently high, the volatility of $\hat{\pi}_t$ (measured by the inflation variance ϕ_π) due to unanticipated cost-push shocks is less than the volatility due to analogous anticipated shocks:*

$$\text{If } \gamma \to 0 \text{ and if } \omega \text{ is large enough, then } \phi_{\pi,q=0} < \phi_{\pi,q>0}$$

$$\text{for all } q > 0.$$

Provided γ-values are very close to zero (i.e., GHH preferences) and the levels of price rigidity are sufficiently high, similar findings as those for the output volatility under Proposition 1 hold true for the inflation volatility ϕ_π. The inflation volatility monotonically increases with an increasing anticipation horizon q and also with an increasing Calvo parameter ω until a maximum value of the anticipation horizon q^{max} is reached.[12] Again, the maximum values of q^{max} depend on the degree of nominal rigidity ω—the lower the level of nominal rigidity, the higher the maximum value of the anticipation horizon.

If, by contrast, the price rigidity is very low (i.e., $\omega \leq 0.40$ in the case of $\gamma = 0.001$ and $\omega \leq 0.25$ in the case of $\gamma = 0.001$, respectively) and thus prices are relatively flexible, the inflation volatility due to news shocks can be lower than the corresponding volatility due to unexpected cost-push shocks.

Another exception that yields lower volatility in the context of news shocks is specified in the following Proposition 3.

[12] Compared to the non-monotonic relationship between output volatility and price rigidity, Table 2-3 in the appendix documents a positive correlation between inflation volatility and the degree price rigidity.

Proposition 3. *If $\gamma = 1$, and if the degree of price rigidity ω is sufficiently low, the inflation variance ϕ_π decreases monotonically with increasing anticipation horizon q and increases monotonically with increasing price rigidity ω:*

$$\text{If } \gamma = 1 \text{ and } 0 < \omega < 0.75, \text{ then } \phi_{\pi,q=0} > \phi_{\pi,q>0}$$

$$\text{for all } q > 0.$$

In this case, news shocks can cause lower inflation volatility than unexpected shocks of the same form.

For a high degree of price stickiness (i.e., $\omega \geq 0.75$), the anticipation of a cost-push shock can also lead to a lower volatility compared to unexpected shocks—but only when the shock is announced no sooner than five quarters before it materializes.

The following final proposition results from prior presented findings and addresses welfare dynamics. Remember, according to equation (2-13), welfare losses are defined as a function that weights the deviations of inflation and output from their initial steady state values.

Proposition 4. *Welfare losses J_t induced by anticipated cost-push shocks are always larger than welfare losses due to unanticipated shocks of the same size:*

$$J_{q=0} < J_{q>0} \text{ for all } q > 0,$$

$$\text{all } \omega > 0, \text{ and } \gamma \in (0,1).$$

The later agents learn about a forthcoming shock *(the smaller q)*, the lower the social welfare loss. Assuming, for example, $\omega = 0.75$ and $\gamma = 0.01$, an unanticipated cost shock leads to $J_{q=0}^{\gamma=0.01} = 4.95832$, while a shock announced three periods ahead leads to $J_{q=3}^{\gamma=0.01} = 9.45690$. Table 2-1 also contrasts the highly different loss development in cases of low and high price stickiness. Thus, if price rigidity is large, i.e., just a small proportion $1 - \omega$ of all firms is able to adjust prices in response to the economic environment, the sustained welfare losses are relatively large. Conversely, a low degree of price rigidity induces relatively low welfare losses.

Moreover, the analyses show that for $\gamma = 1$, the welfare loss J_t is a monotonically increasing function in the lead time q and parameter ω. For γ-values near zero, the facts stated in Propositions 1 and 2 hold true. Hence, the loss increases monotonically in the anticipation horizon q at least until a maximum value of lead time q^{max} is reached.[13] Nevertheless, outside the

[13] Actually, in the case of $\gamma = 0.001$ and $\omega = 0.75$, investigations do not reveal any upper endpoint, i.e., the loss shows a non-decreasing path for all q.

interval, welfare losses are still larger than those induced by unexpected shocks. Thus, news shocks constitute a greater burden for an economy than unexpected shocks.

In addition to Table 2-1 and Table 2-3, Figure 2-1 visualizes and provides proof of the aforementioned propositions and summarizes the main sources of welfare dynamics. Therefore, Figure 2-1 contrasts the differentiated movements in the volatilities of inflation, output, and price level of anticipated shocks compared to unanticipated shocks.

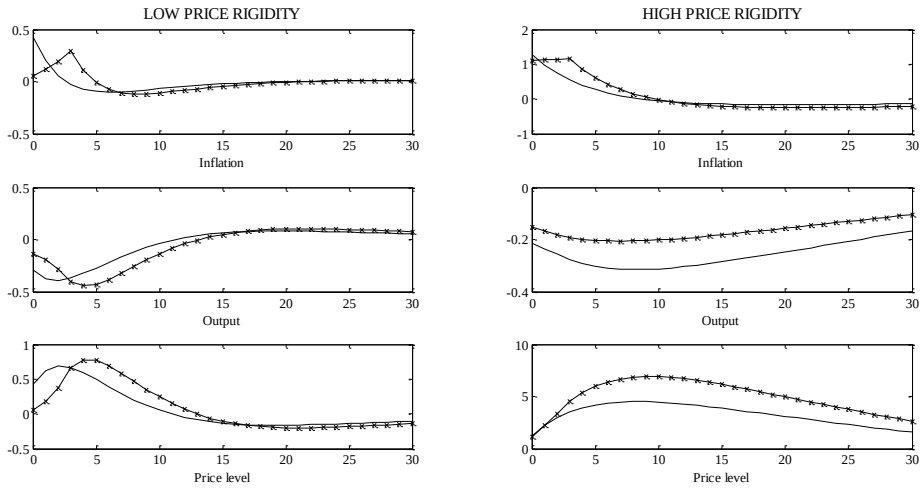

Figure 2-1 Impulse Responses to (Un)Anticipated Temporary Cost-Push Shocks with Unrestricted Monetary Policy under Commitment.

Notes: The vertical axes show percentage deviations from the steady state. The horizontal axes show anticipation horizon q. The time unit is one quarter. Solid lines are the responses to an unanticipated cost-push shock. Solid lines with crosses are the responses of an anticipated cost-push shock. Graphs on the left panel are based on a low ($\omega = 0.25$) degree of price rigidity. Graphs on the right panel are based on a high ($\omega = 0.75$) degree of price rigidity.

In particular, welfare dynamics are induced by two opposing mechanisms. On one hand, in an "anticipation effect", news shocks cause a decline in the initial reaction of forward-looking macroeconomic fundamentals directly at the time of announcement. The sooner agents learn about a forthcoming shock *(the larger q)*, the lower the immediate reactions in inflation, output, and price level. On the other hand, in a "persistence effect", news shocks cause a larger persistence of the response of endogenous variables than unexpected shocks. Note that following Merkl and Snower (2009) and Wohltmann and Winkler (2009), persistence is measured as a variable's intertemporal total deviation from its steady state over time. The persistence effect is amplified by the length of the span between the anticipation and materialization of a shock.

Hence, the sooner a cost shock is announced, the larger the persistence effect on key macroeconomic variables.[14]

Finally, one important finding concerning parameter γ stands out. While this parameter constitutes a key element of the news-driven RBC model proposed by JR (2009), in the present analysis, it is not possible to give a general statement of its impact on social welfare.[15] Although one might expect a positive correlation between volatility dynamics and parameter γ due to the controlled strength of the wealth effect, this is not the case. In other words, GHH preferences ($\gamma = 0$, i.e., full absence of the wealth effect) do not yield the lowest total variation of inflation, output, and subsequently, welfare loss in response to (un)anticipated cost-push shocks.

2.3.2 Optimal Simple Rules

This subsection discusses the structure and welfare implications of (optimal) simple policy rules (OSR) in the presence of cost-push shocks. The monetary rules employed are variants of the canonical Taylor rule (see Taylor, 1993) and are conditional upon both inflation and output targeting. The values of the coefficients δ_y and δ_π result from the minimization of the loss function (2-13) and depend on the underlying rule. The analyzed set of rules supports the validity of the previously acquired results: welfare losses that arise due to anticipated cost-push shocks are greater than the corresponding losses of unpredictable shocks of equal magnitude.

The findings of this subsection are reported in Table 2-2. The table shows the absolute welfare losses arising from each simple Taylor-type interest rate rule in relation to a temporary (un)anticipated cost-push shock. To facilitate comparison of the efficiency of a single rule with the performance of unrestricted monetary policy, the percentage of the welfare loss from a rule relative to the loss arising from the optimal unrestricted monetary policy is reported as well. Therefore, the first interior row of Table 2-2 repeats the loss results generated by the optimal unrestricted monetary policy developed in Section 2.3.1. Moreover, the second interior row of the table displays the results under the ad hoc given Taylor rule as a reference case.

[14] Wohltmann and Winkler (2009) provide a more detailed proof of both the anticipation and persistence effects in the canonical NK model.

[15] In particular, JR (2009) combine three elements—variable capital utilization, investment adjustment costs, and the aforementioned special preference structure—in a RBC model that generate positive comovement in macroeconomic fundamentals in response to anticipated shocks.

Table 2-2 Welfare Loss due to (Un)Anticipated Shocks for Various Monetary Policy Rules.

Monetary policy		$J_{q=0}$	$J^r_{q=0}$	$J_{q=3}$	$J^r_{q=3}$	$J_{q=8}$	$J^r_{q=8}$
Unrestricted optimal policy		4.9583	100.00%	9.4569	100.00%	14.5764	100.00%
Ad hoc Taylor rule [a]		7.1653	144.51%	13.2535	140.15%	19.7976	135.82%
OSR I-VII							
I	$i_t = f(\pi_t, y_t)$	5.5668	112.27%	10.6923	113.06%	16.8922	115.89%
II	$i_t = f(\pi_t, y_t, E_t\pi_{t+1})$	5.5668	112.27%	10.6916	113.06%	16.8631	115.69%
III	$i_t = f(\pi_t, y_t, E_t y_{t+1})$	5.5668	112.27%	10.6916	113.06%	16.8630	115.69%
IV	$i_t = f(\pi_t, y_t, E_t\pi_{t+1}, E_t y_{t+1})$	5.5668	112.27%	10.6916	113.06%	16.8625	115.68%
V	$i_t = f(y_t, E_t\pi_{t+1})$	5.6111	113.17%	11.1333	117.73%	18.1669	124.63%
VI	$i_t = f(\pi_t, E_t y_{t+1})$	5.5668	112.27%	10.7006	113.15%	16.9453	116.25%
VII	$i_t = f(E_t\pi_{t+1}, E_t y_{t+1})$	5.7896	116.77%	11.3705	120.23%	18.3398	125.82%

Notes: For each monetary policy rule, this table presents the absolute welfare loss $J_{q\geq 0}$ due to a temporary (un)anticipated cost-push shock ($\rho = 0.8$). The table also presents the loss $J^r_{q\geq 0}$ (in percentage terms) under the considered rule relative to the loss generated with optimal unrestricted monetary policy developed in Section 2.3.1 (repeated in the first interior row of Table 2-2). Parameter γ is set to 0.01.

[a] The ad hoc given Taylor rule $i_t = i^* + \delta_\pi(\hat{\pi}_t - \hat{\pi}^*) + \delta_y \hat{y}_t$ follows an explicit instrument rule originally proposed by Taylor (1993). Its coefficients for inflation and output do not result of the minimization of the loss function (2-13); instead, they are exogenously given by $\delta_\pi = 1.5$ and $\delta_y = 0.5$. Furthermore, the rule incorporates the target level of inflation $\hat{\pi}^*$ and the natural interest rate i^* (i. e., $\hat{\pi}^* = i^* = 0$).

It is easy to see that the ad hoc given Taylor rule leads to the highest welfare loss and therefore constitutes the worst opportunity for a central bank. Apart from this, the results indicate that the lowest welfare loss always comes along with a central bank's monetary policy in which interest rate rules respond not only to contemporaneous but also to expected values of inflation and output (see OSR IV). These rules present a reasonable choice for the monetary authority regardless of the timing of cost-push shocks. These findings are in keeping with those of Winkler and Wohltmann (2011), who investigate news shocks in the baseline and in a hybrid version of the NK model and therefore assume a normal and hybrid NK IS curve, respectively.

Furthermore, also in line with Winkler and Wohltmann (2011), Table 2-2 reveals the same loss development of the exclusively current-looking OSR I as of rules that include additional forward-looking dimensions (e.g., OSR II). Thus, they respond to both contemporaneous and expected future economic conditions. However, this result only holds true in the context of unanticipated cost shocks. If shocks are announced, the additional inclusion of forward-looking elements can cause a welfare gain, albeit only slightly.

Of note is that interest rate rules that are purely forward-looking—and therefore respond solely to expected economic conditions—generate the largest welfare losses regardless of whether or not cost-push shocks are anticipated. In the case of unforeseen shocks, OSR VII involves an

approximately 17% higher loss than unrestricted monetary policy. Similar results hold given disturbances announced three and eight quarters before they hit an economy. Applying OSR VII amplifies the loss by approximately 20 and 26%, respectively.

Finally, Table 2-2 reveals another interesting result: OSR V, which excludes current inflation, yields larger losses than rules that react to current inflation (see OSR I-IV and VI). In particular, the different welfare dynamics of these rules can clearly be seen in the presence of anticipated shocks.

2.4 Conclusion

By embedding a nonseparable Jaimovich/Rebelo (2009)-type utility function in the baseline NK model, this article suggests a novel approach to explore news shocks and their implications for monetary policy. At present, there is no consensus among economists regarding the (de)stabilizing effects of news shocks; however, by amplifying the volatility of macroeconomic variables (summarized by inflation and output volatility), this study offers evidence that the anticipation of forthcoming cost-push shocks has a welfare-reducing effect. Unrestricted monetary policy under commitment constitutes the optimal policymaker's choice. Furthermore, an investigation of various Taylor-type interest rules reveals that rules that respond to both contemporaneous and expected future macroeconomic conditions constitute an effective monetary instrument to keep welfare losses to a minimum.

Finally, although one might expect social welfare gains due to agents' improved perceptions of economic needs due to a higher availability of economic data, the results of this study indicate the opposite. Based on this, it might not be rational for a central bank to announce monetary policy responses to economic shocks in advance.

2.5 Appendix A. Log-linearized System of Equations

Notice that variables with overbars and without a time index indicate steady state values. Variables with hats represent percentage deviation from a steady state. Therefore, a first-order Taylor series expansion around the steady state is as follows:

$$\hat{g} = \frac{dG}{\bar{G}} = \frac{1}{\bar{G}}(G - \bar{G}) \approx log\, G - log\, \bar{G}$$

To enhance readability, equations (A1) and (A2) and equation (A4) are solved for $\hat{\lambda}_{1,t}$ and $\hat{\lambda}_{2,t}$, respectively.

2.5.1 Endogenous Equations

Optimality condition for consumption $\hat{c}_t$:

$$\hat{\lambda}_{1,t} = \frac{\bar{\lambda}_1 + \bar{X}^{-\sigma}}{\bar{\lambda}_1}\hat{\lambda}_{2,t} + (\gamma - 1)\frac{\bar{\lambda}_1 + \bar{X}^{-\sigma}}{\bar{\lambda}_1}\hat{c}_t + (1-\gamma)\frac{\bar{\lambda}_1 + \bar{X}^{-\sigma}}{\bar{\lambda}_1}\hat{s}_{t-1} + \sigma\frac{\bar{X}^{-\sigma}}{\bar{\lambda}_1}\hat{x}_t \tag{A 1}$$

with the abbreviation $\bar{\lambda}_1 + \bar{X}^{-\sigma} = \gamma\bar{C}^{\gamma-1}\bar{S}^{1-\gamma}\bar{\lambda}_2$, where $\bar{\lambda}_1 + \bar{X}^{-\sigma} = \gamma\bar{C}^{\gamma-1}\bar{S}^{1-\gamma}\bar{\lambda}_2$, and $\bar{X} = \bar{N} - \psi\bar{N}^{\theta+1}$.

Furthermore, $\bar{\lambda}_2 = \frac{\psi}{(1+\beta(\gamma-1))}\bar{N}^{\theta}\bar{X}^{-\sigma}$, where $\psi = \left\{\frac{\gamma}{1+\beta(\gamma-1)} + \theta\bar{\mu}\right\}^{-1}\bar{N}^{-\theta}$, and $\bar{\mu} \equiv \frac{\eta}{\eta-1}$.

As in Galí (2008), the price mark-up η is assumed to be 20% in a steady state, which is achieved by setting $\eta = 6$. The calibrated $\bar{N} = \frac{8}{24} = \frac{1}{3}$ implies eight working hours per day.

Optimality condition for labor supply $\hat{n}_t$:

$$\hat{\lambda}_{1,t} = -\sigma\hat{x}_t + (\theta - 1)\hat{n}_t + \hat{s}_t - (\hat{w}_t - \hat{p}_t) \tag{A 2}$$

Optimality condition for geometric average of the current and past consumption level $\hat{s}_t$ and corresponding Lagrangian multiplier $\hat{\lambda}_{2,t}$:

$$\hat{s}_t = \gamma\hat{c}_t + (1-\gamma)\hat{s}_{t-1} \tag{A 3}$$

$$\hat{\lambda}_{2,t} = \frac{1}{\bar{\lambda}_2}\big(\psi\theta\bar{N}^{\theta}\bar{X}^{-\sigma}\hat{n}_t - \sigma\psi\bar{N}^{\theta}\bar{X}^{-\sigma}\hat{x}_t - \beta(\gamma-1)\gamma\bar{\lambda}_2 E_t\hat{c}_{t+1} - \beta(\gamma-1)\bar{\lambda}_2 E_t\hat{\lambda}_{2,t+1} + \gamma\beta(\gamma-1)\bar{\lambda}_2\hat{s}_t\big) \tag{A 4}$$

Log-linearized version of the auxiliary variable $X_t = C_t - \psi N_t^{\theta} S_t$ representing the composite index of consumption, labor, and consumption smoothing:

$$\hat{x}_t = \frac{\bar{C}}{\bar{X}}\hat{c}_t + \theta\frac{\bar{X} - \bar{C}}{\bar{X}}\hat{n}_t + \frac{\bar{X} - \bar{C}}{\bar{X}}\hat{s}_t \tag{A 5}$$

Optimal bonds decision:

$$\hat{\lambda}_{1,t} = E_t\hat{\lambda}_{1,t+1} + i_t - E_t\hat{\pi}_{t+1} \tag{A 6}$$

Goods market clearing condition:

$$\hat{y}_t = \hat{c}_t \tag{A 7}$$

Production function $\hat{y}_t$:

$$\hat{y}_t = \hat{n}_t + \hat{a}_t \tag{A 8}$$

Forward-looking Phillips curve $\hat{\pi}_t$ as a function of real marginal costs $\widehat{mc}_t$, including a cost shock $\hat{e}_t$:

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\omega)(1-\omega\beta)}{\omega} \widehat{mc}_t + \hat{e}_t \tag{A 9}$$

Real marginal costs $\widehat{mc}_t$:

$$\widehat{mc}_t = \hat{w}_t - \hat{p}_t - \hat{a}_t \tag{A 10}$$

Law of price:

$$\hat{\pi}_t = \hat{p}_t - \hat{p}_{t-1} \tag{A 11}$$

Real interest rate $\hat{r}_t$:

$$\hat{r}_t = i_t - E_t \hat{\pi}_{t+1} \tag{A 12}$$

Nominal interest rate i_t following an ad hoc given Taylor rule:

$$i_t = i^* + \delta_\pi(\hat{\pi}_t - \hat{\pi}^*) + \delta_y \hat{y}_t \tag{A 13}$$

2.5.2 Exogenous Processes

Cost shock:

$$\hat{e}_t = \rho \hat{e}_{t-1} + \varepsilon^e_{t-q} \tag{A 14}$$

Technology shock:

$$\hat{a}_t = \rho \hat{a}_{t-1} + \varepsilon^a_{t-q} \tag{A 15}$$

2.6 Appendix B. Tables

Table 2-3 Variances and Welfare Losses in Response to (Un)Anticipated Shocks with Unrestricted Monetary Policy, β=0.99.

	Output variance ϕ_y					Inflation variance ϕ_π					Welfare loss J_t				
ω	0.25	0.40	0.55	0.66	0.75	0.25	0.40	0.55	0.66	0.75	0.25	0.40	0.55	0.66	0.75
q			$\gamma = 0.001$					$\gamma = 0.001$					$\gamma = 0.001$		
0	0.98676	1.86746	2.01111	1.60097	1.14435	0.23083	1.10043	2.75652	4.18872	5.24832	0.72421	2.03416	3.76207	4.98921	5.82050
1	1.21970	2.51157	2.80828	2.26748	1.63204	0.21719	1.27870	3.50868	5.50866	7.01013	0.82704	2.53448	4.91282	6.64240	7.82615
2	1.34644	3.07628	3.63900	3.00515	2.18737	0.19326	1.33650	4.06977	6.66065	8.65180	0.86648	2.87464	5.88927	8.16323	9.74548
3	1.40795	3.54493	4.47368	3.79738	2.80282	0.17693	1.33204	4.47980	7.66284	10.18035	0.88090	3.10450	6.71665	9.56153	11.58176
4	1.43483	3.91908	5.29067	4.62970	3.47137	0.16832	1.29913	4.77125	8.53158	11.60246	0.88573	3.25867	7.41660	10.84643	13.33815
8	1.44700	4.70463	8.14225	8.13342	6.55282	0.16350	1.14695	5.20570	10.94626	16.34794	0.88700	3.49927	9.27682	15.01297	19.62435
12	1.44489	4.89934	10.14675	11.54149	10.03869	0.16478	1.08467	5.11754	12.17413	19.83923	0.88722	3.53434	10.19092	17.94487	24.85858
q^{max}	7	15	30	∞	∞	0	2	9	20	40	6	15	30	45	∞
			$\gamma = 0.01$					$\gamma = 0.01$					$\gamma = 0.01$		
0	0.89289	1.45127	1.52264	1.32974	1.10045	0.28858	1.09620	2.38449	3.48409	4.40810	0.73502	1.82184	3.14581	4.14896	4.95832
1	1.10132	1.93775	2.10782	1.86880	1.55983	0.27996	1.27010	2.99283	4.51533	5.81510	0.83062	2.23897	4.04675	5.44973	6.59501
2	1.20087	2.34434	2.69466	2.44705	2.07056	0.25457	1.31873	3.40599	5.35238	7.05653	0.85500	2.49090	4.75332	6.57590	8.09181
3	1.22885	2.65590	3.25715	3.04630	2.62175	0.23952	1.30351	3.66947	6.02147	8.14602	0.85394	2.63146	5.29804	7.54462	9.45690
4	1.22012	2.87434	3.77709	3.65116	3.20346	0.23738	1.26239	3.82066	6.54631	9.09650	0.84744	2.69956	5.70921	8.37188	10.69823
8	1.15690	3.08242	5.26407	5.90265	5.66748	0.27552	1.14587	3.82634	7.59753	11.74262	0.85397	2.68708	6.45837	10.54885	14.57636
12	1.19383	2.88504	5.80884	7.57757	8.04410	0.29546	1.20611	3.58873	7.68296	13.02162	0.89238	2.64863	6.49315	11.47175	17.04367
q^{max}	3	7	13	21	35	0	3	6	10	18	2	5	10	16	25
			$\gamma = 1$					$\gamma = 1$					$\gamma = 1$		
0	0.01346	0.07699	0.34428	0.90676	1.68575	0.00006	0.00190	0.03059	0.18765	0.74496	0.00679	0.04039	0.20273	0.64103	1.58784
1	0.01347	0.07802	0.37863	1.10932	2.22803	0.00006	0.00159	0.02305	0.17116	0.82567	0.00680	0.04060	0.21237	0.72582	1.93969
2	0.01347	0.07804	0.38554	1.21395	2.66488	0.00006	0.00158	0.02087	0.15000	0.82382	0.00680	0.04060	0.21364	0.75697	2.15626
3	0.01347	0.07804	0.38677	1.26343	2.99674	0.00006	0.00158	0.02042	0.13670	0.79121	0.00680	0.04060	0.21381	0.76842	2.28958
4	0.01347	0.07804	0.38697	1.28564	3.23947	0.00006	0.00158	0.02035	0.12980	0.75190	0.00680	0.04060	0.21383	0.77262	2.37164
8	0.01347	0.07804	0.38701	1.30175	3.67279	0.00006	0.00158	0.02033	0.12415	0.64778	0.00680	0.04060	0.21383	0.77502	2.48417
12	0.01347	0.07804	0.38701	1.30221	3.76428	0.00006	0.00158	0.02033	0.12396	0.61819	0.00680	0.04060	0.21383	0.77506	2.50033
q^{max}	∞	∞	∞	∞	∞	-	-	-	-	1	∞	∞	∞	∞	∞

Notes: The table lists the relative output variance ϕ_y, relative variance of inflation ϕ_π, and welfare loss J_t in response to a temporary (un)anticipated cost-push shock for various degrees of price rigidity ω. The letter q refers to the anticipation horizon. Parametrizations $\gamma = 0.001$ and $\gamma = 0.01$, as estimated by Schmitt-Grohé and Uribe (2012), denote GHH preferences, whereas $\gamma = 1$ denotes KPR preferences. Parameter β is set to 0.99. Moreover, the table documents the upper endpoint q^{max} of the time interval $[0, q^{max}]$. Up to q^{max}, the volatility of a variable is monotonically increasing in the lead time q. An infinity sign is used if no upper endpoint q^{max} exists, i.e., the volatility is non-decreasing in q over all investigated anticipation horizons. A dash is used in the exceptional case in which volatility is monotonically decreasing in q.

Table 2-4 Variances and Welfare Losses in Response to (Un)Anticipated Shocks with Unrestricted Monetary Policy, β=1.

	Output variance ϕ_y					Inflation variance ϕ_π					Welfare loss J_t				
ω	0.25	0.40	0.55	0.66	0.75	0.25	0.40	0.55	0.66	0.75	0.25	0.40	0.55	0.66	0.75
q			$\gamma = 0.001$					$\gamma = 0.001$					$\gamma = 0.001$		
0	1.55654	1.95200	1.47167	0.92285	0.52937	0.68360	2.16950	3.98155	5.14002	5.86444	1.46187	3.14550	4.71739	5.60144	6.12912
1	2.04794	2.70487	2.08359	1.31707	0.75850	0.74974	2.70515	5.21981	6.85994	7.89384	1.77371	4.05758	6.26161	7.51847	8.27309
2	2.43305	3.46233	2.75900	1.76678	1.02409	0.74032	3.05952	6.28530	8.45699	9.84397	1.95685	4.79069	7.66480	9.34038	10.35601
3	2.71521	4.19396	3.48178	2.26592	1.32414	0.70551	3.28156	7.19804	9.93837	11.71725	2.06312	5.37854	8.93894	11.07132	12.37932
4	2.91220	4.88047	4.23802	2.80881	1.65668	0.66768	3.40843	7.97600	11.31092	13.51607	2.12378	5.84867	10.09501	12.71533	14.34441
8	3.21382	7.02831	7.38358	5.31766	3.27507	0.58281	3.42856	10.03695	15.83774	20.01235	2.18972	6.94272	13.72874	18.49657	21.64989
12	3.24229	8.26362	10.37835	8.16451	5.27368	0.57026	3.22455	10.95895	19.08567	25.49267	2.19141	7.35636	16.14812	23.16792	28.12951
q^{max}	12	25	∞	∞	∞	0	6	17	35	∞	10	22	40	∞	∞
			$\gamma = 0.01$					$\gamma = 0.01$					$\gamma = 0.01$		
0	1.02223	1.43987	1.34453	1.08836	0.84094	0.41527	1.37260	2.69495	3.72950	4.56694	0.92638	2.09254	3.36722	4.27368	4.98740
1	1.29253	1.94693	1.87385	1.53644	1.19600	0.42432	1.63159	3.42102	4.86169	6.04339	1.07059	2.60505	4.35795	5.62991	6.64139
2	1.45109	2.39953	2.42067	2.02596	1.59597	0.39559	1.74076	3.94793	5.80643	7.36352	1.12114	2.94053	5.15826	6.81941	8.16150
3	1.52165	2.77601	2.96296	2.54367	2.03382	0.36902	1.76041	4.31447	6.58508	8.53822	1.12985	3.14841	5.79595	7.85692	9.55514
4	1.53521	3.06924	3.48372	3.07783	2.50293	0.35600	1.73204	4.55389	7.21739	9.57801	1.12360	3.26666	6.29575	8.75631	10.82948
8	1.44044	3.52508	5.15010	5.19226	4.57381	0.39639	1.55628	4.74269	8.62595	12.58331	1.11661	3.31882	7.31774	11.22208	14.87022
12	1.44478	3.35756	5.99716	6.96716	6.71983	0.44458	1.57013	4.47601	8.89899	14.16018	1.16697	3.24891	7.47459	12.38257	17.52010
q^{max}	4	8	15	24	35	0	3	7	12	18	3	9	11	18	25
			$\gamma = 1$					$\gamma = 1$					$\gamma = 1$		
0	0.01355	0.07789	0.34999	0.92127	1.69145	0.00006	0.00194	0.03164	0.19605	0.78439	0.00684	0.04089	0.20663	0.65669	1.63011
1	0.01356	0.07897	0.38586	1.13129	2.24385	0.00006	0.00162	0.02384	0.17997	0.87542	0.00684	0.04110	0.21678	0.74562	1.99734
2	0.01356	0.07899	0.39330	1.24235	2.69677	0.00006	0.00161	0.02151	0.15789	0.87876	0.00684	0.04110	0.21816	0.77907	2.22715
3	0.01356	0.07899	0.39467	1.29620	3.04730	0.00006	0.00161	0.02102	0.14355	0.84730	0.00684	0.04110	0.21835	0.79165	2.37095
4	0.01356	0.07899	0.39490	1.32099	3.30865	0.00006	0.00161	0.02092	0.13589	0.80662	0.00684	0.04110	0.21837	0.79638	2.46094
8	0.01356	0.07899	0.39495	1.33972	3.79445	0.00006	0.00161	0.02091	0.12932	0.69113	0.00684	0.04110	0.21838	0.79918	2.58835
12	0.01356	0.07899	0.39495	1.34031	3.90541	0.00006	0.00161	0.02091	0.12908	0.65518	0.00684	0.04110	0.21838	0.79924	2.60789
q^{max}	∞	∞	∞	∞	∞	-	-	-	-	2	∞	∞	∞	∞	∞

Notes: The table lists the relative output variance ϕ_y, relative variance of inflation ϕ_π, and welfare loss J_t in response to a temporary (un)anticipated cost-push shock for various degrees of price rigidity ω. The letter q refers to the anticipation horizon. Parametrizations $\gamma = 0.001$ and $\gamma = 0.01$, as estimated by Schmitt-Grohé and Uribe (2012), denote GHH preferences, whereas $\gamma = 1$ denotes KPR preferences. Parameter β is set to 1. Moreover, the table documents the upper endpoint q^{max} of the time interval $[0, q^{max}]$. Up to q^{max}, the volatility of a variable is monotonically increasing in the lead time q. An infinity sign is used if no upper endpoint q^{max} exists, i.e., the volatility is non-decreasing in q over all investigated anticipation horizons. A dash is used in the exceptional case in which volatility is monotonically decreasing in q.

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3 The Olympic Games as a News Shock: Macroeconomic Implications

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Abstract

The awarding of the Olympic Games to a certain city or the announcement of a city's Olympic bid may be considered as a news shock that affects agents' market expectations. A news shock implies potential impacts on the dynamic adjustment process that change not only the volatility but also the long-run steady state levels of endogenous economic variables. In this study, we contribute to and extend previous researchers' attempts to empirically test for the Olympic Games as a news shock by implementing full structural models and by matching Olympic hosts and bidders to structurally similar countries.

JEL classification: E62, E65, F1, L83

Keywords: Anticipated shock, Olympic Games, GDP growth, matching, entropy balancing, mega event

3.1 Introduction

Economic development cannot be explained solely on the basis of exogenous fundamental shocks (Akerlof and Shiller, 2010; Cochrane, 1994). Since the path-breaking contributions of Beaudry and Portier (2004, 2006) regarding expectation-driven business cycles, a growing body of literature has examined anticipated shocks, the so-called news shocks, as a potential source of economic fluctuation (see, for instance, Barsky and Sims, 2011; Davis, 2007; Jaimovich and Rebelo, 2009; Schmitt-Grohé and Uribe, 2012).

News shocks do not constitute an exogenous change in current macroeconomic fundamentals. However, these shocks may affect the agents' current market expectations. In other words, agents receive a signal today regarding economic developments tomorrow, such as higher productivity growth, and immediately adjust their contemporaneous investment, consumption, and work decisions (Fève et al., 2009; Jaimovich and Rebelo, 2009). Consequently, the announcement of forthcoming shocks may significantly affect the dynamic adjustment process by changing the volatility and persistence of endogenous economic variables (Barsky and Sims, 2011; Fève et al., 2009; Jaimovich and Rebelo, 2009).

In one of the earliest attempts to empirically implement the news shock theory in the field of sports economics, Brückner and Pappa (BP) (2015) analyze the economic effects of bidding for (or hosting) the Olympic Games on macroeconomic indicators such as investment, consumption, and output. These researchers indicate that the decision to apply for the games increases output significantly eight and three years before the actual event by 0.98 and 0.77 percentage points, respectively. For Olympic hosts, the researchers also find positive effects of 1.74, 2.60, and 1.41 percentage points at three, four and five years preceding the games, respectively. The cumulative effect on output from ten years before the games to seven years after the games reaches approximately 15% (BP, 2015, p. 1352).

Olympic economic statistics may be heavily influenced by political considerations, and there is minimal agreement regarding the correct measurement of the size of Olympic investments. However, even using the highest investment figures available, the average Olympic investments for the Olympics from 1992 to 2012 did not exceed an unweighted 1% of national gross domestic product (GDP) per year; this figure is heavily influenced by the cases of Barcelona, Spain, in 1992 and Athens, Greece, in 2004 (Table 3-1). BP's (2015) implicit investment multipliers of 15 for the Olympic Games are notably large, compared to the majority of the latest findings in fiscal policy research with multipliers in a range of zero to one (Coenen et al., 2012).

In addition, the previous econometric ex post studies of Olympic Summer Games, although admittedly not based on the news shock theory, have been less favorable. Baade and Matheson (2002) examine the employment effects of the 1996 Atlanta Games. In a different estimated model, the researchers include periods leading to 1993 and test for impacts until 1997. In some specifications, the researchers discover the negative impacts of the Atlanta Olympics. In its most optimistic estimate, the study indicates a maximum of 42,500 additional jobs in the Olympic venue counties in the state of Georgia, United States, at least 40% of which were transitory. This figure implies a 3.42% increase in local employment in Atlanta and a 0.05% increase in U.S. employment.

Examining the 1996 Atlanta Olympic Games, Hotchkiss et al. (2003) check for an alternative intervention point from 1991 to 1998 and find a best fit for 1994, comparable to two yearly leads. The researchers' data end in 2000, which allows them to examine any Olympic effects with a maximum of four lags. The researchers isolate a level shift of employment of 17.2% in Georgia counties that are affiliated with and close to the activities of the Olympic Games in Atlanta, which can be translated into approximately 293,000 additional jobs created. In a separate analysis, the researchers indicate a trend shift in employment of 0.2 percentage point. Using the same data but simultaneously allowing for a level shift and trend shifts, Feddersen and Maennig (2013a) are unable to reject the hypothesis that the 1996 Olympics had no significant impact on the employment figures. In a sectoral analysis of the Atlanta Games using monthly data, Feddersen and Maennig (2013b) suggest a small increase of 29,000 jobs, exclusively for the Atlanta Olympic month, exclusively in Fulton County and exclusively in a few specific sectors.

Comparing different ex ante and ex post periods with as much as six-year leads and twelve-year lags, Jasmand and Maennig (2008) do not find any systematic income or employment effects from the Olympic Games in Munich (1972). Analyzing the Olympic Games from 1960-2012, Rose and Spiegel (2011) suggest a permanent export boost of 39% in Olympic host countries; however, Maennig and Richter (2012) demonstrate that these empirical findings suffer from selection bias.[16] Testing the effects of the Olympic Games in Seoul in 1988, Barcelona in 1992, Sydney in 2000, and Beijing in 2008 on tourism and foreign exchange earnings with an autoregressive integrated moving average (ARIMA) model, Mitchell and Steward (2015)

[16] Using the data of Rose and Spiegel (2011), Song (2010) indicate the negative effects of the Olympics on tourism.

exclusively find negative Olympic impacts for the host countries, with the exception of a positive level shift of tourist numbers for South Korea.[17]

Thus, it appears to be worthwhile to attempt to fill the gap between the findings of BP and the remainder of the relevant literature. Notably, the BP's study is exceptional because the remainder of the literature did not control for ten yearly leads and lags when measuring the effects of the Olympic Games. This control may be important according to the insights of the news theory: Long before the actual event and before a city is awarded the designation of Olympic host, there may be anticipation shocks. In the following study, we also allow for ten yearly leads and lags.

BP do not follow the much richer and multivariate approach of the majority of other analyses and thus do not consider the well-established determinants of economic growth; this approach leads to a potential omitted variable bias. In the following study, we refer to the literature on economic growth, which has identified investment growth, government spending growth, fertility, life expectancy, and human capital, among others, as key determinants (Barro, 1991, 2003).[18]

In addition, the BP's analyses compare the economic performance of some of the most privileged countries in the world, including Australia, Canada, France, Germany, Japan, the United Kingdom, and the United States, that bid for the Olympic Games to those of all other countries in the world, including much less privileged countries such as Uganda, Burundi, and Gambia. Therefore, the results may be influenced by a sample selection bias. We use propensity score matching (PSM) to identify countries that are structurally similar to the bidding and hosting countries but are not bidders themselves.

In this study, we combine the insights of news shock theory and apply an appropriate number of leads and lags. We also combine the insights regarding growth and business cycles from empirical studies with the conventional wisdom regarding intervention studies and the need to correctly match treatment and control groups. Overall, we do not find significant economic effects regarding the Olympic Games. We find that these results are robust to the inclusion of a substantially revised and newer data set.

[17] For the empirical tests regarding the Olympic Winter Games (Salt Lake City 2002), see Baade et al. (2010), who find positive consumption effects in the hospitality sector that were offset by larger negative consumption effects in other industries. For the same Olympics, Baumann et al. (2012) indicate a small effect of an additional 4,000–7,000 jobs, concentrated in the leisure industry but minimal to no effect on employment after twelve months.

[18] Table 3-1 shows that the proportions of Olympic investment costs in comparison to a country's overall investment volume are negligible. Thus, it is difficult to argue that including investment (as well as government spending) in multivariate regression models negates the effects that the Olympics have on economic growth through investment and government spending.

The remainder of this article is organized as follows. Section 3.2 presents the empirical strategy and results. Section 3.3 discusses various robustness checks. Section 3.4 concludes the paper.

Table 3-1 Olympic Investment in Relation to Host Country GDP/Investment.

		GDP (in billion. $US)	Investment (in billion $US)	Olympic Investment (in billion $US)		Maximum reported Olympic Investment in relation to (in billion $US)			
Olympic Games	Host City	average (Olympic year [t-0] – [t-8])	average (Olympic year [t-0] – [t-8])	reported minimum	reported maximum	GDP (Olympic year)	GDP (Olympic year + 8 years preceding)	Investment (Olympic year)	Investment (Olympic year + 8 years preceding)
1992	Barcelona	0,481.0	0,117.6	06.2	08.0	1.29%	0.19%	05.12%	0.76%
1996	Atlanta	6,358.0	1,205.3	01.2	02.5	0.03%	0.00%	00.16%	0.02%
2000	Sydney	0,425.0	0,100.0	03.0	03.4	0.65%	0.09%	02.84%	0.38%
2004	Athens	0,202.1	0,048.6	10.2	12.1	4.65%	0.67%	17.17%	2.78%
2008	Beijing	5,831.4	2,427.2	14.3	40.0	0.41%	0.08%	00.99%	0.18%
2012	London	2,245.7	0,378.5	09.4	13.7	0.57%	0.07%	03.57%	0.40%

Notes: The GDP data are real purchasing power parity (PPP) adjusted GDP in current prices. The average GDP/investment figures are calculated as the average between the value in the year of the games and the eight years preceding the games. The Olympic investment figures are collected from various sources (Brunet, 1995; Hotchkiss et al., 2003; Kasimati and Dawson, 2009; Mayor of London, 2013; Poynter, 2006; Preuss, 2004; Tziralis et al., 2006).

3.2 Empirical Strategy and Results

Similar to BP, we rely on data from the Penn World Table (PWT), version 7.0, as described by Heston et al. (2011), for the 1950-2009 period. We extend these data by including the standard determinants of economic growth from the World Bank (2011), which include the fertility rate, life expectancy at birth, the stock of human capital (share of tertiary schooling), the degree of international openness, a measure of political stability, and the change in the terms of trade.

The baseline empirical strategy is in accordance with BP.[19] To maintain a short presentation, we restrict ourselves to the effects on GDP per capita growth.[20] Olympic bidders and hosts are denoted as one in the respective year and enter the equations with ten lags and leads to capture the possible effects. In line with BP, we also include the lagged values of the GDP growth rate and of government spending as well as country-level fixed effects and a full set of year fixed effects. Table 3-2 summarizes our main results. Where Model (1) shows the replicated results from BP.

BP include all available countries in their estimation and run ordinary least squares (OLS) regressions that give each country the same weight.[21] To resolve the potential implicit sample selection bias, an extensive strand of literature suggests propensity score matching as a reweighting technique (see, for example, Caliendo and Kopeinig, 2008; Heckmann et al., 1997; Imbens, 2004; Smith and Todd, 2005; Rosenbaum and Rubin, 1983).

The covariates used to estimate the propensity score are required to affect the outcome variable (i.e., GDP growth) and the probability to become a bidder for the Olympic Games; these should preferably be measured before the treatment or should not vary over time (Caliendo and Kopeinig, 2008). Because we attempt to base the matching on the earliest possible year with as many available countries as possible, we encounter a trade-off between the lower data availability in the 1950s and the possibility that later outcomes may previously be influenced by participation in the Olympic Games. We select 1970 as the year and include as covariates the five-year lagged values of GDP, government spending, investment, consumption, and population. We match the bidding countries using one to one nearest neighbor matching and obtain a sample in which the structural differences between the hosts/bidders and the control group countries

[19] We thank Markus Brückner for providing the data set and his do-file.
[20] We also tested the potential effects of the Olympics on investments, with (again) no significant results. Details are available from the authors on request.
[21] The country fixed effects employed by BP's control for time-invariant country-specific variation. However, these effects fail to capture trends that may be specific to certain countries (or certain groups of countries such as the OECD).

are substantially reduced (Appendix C Table 3-4). Appendix C Table 3-5 lists all the countries available in our analysis as well as their inclusion in the subsamples.

Model (2) in Table 3-2 reports the results for the matched sample of countries. The Olympic effects are slightly lower. Most notably, the variance explained by the model is doubled compared with the R^2 of 0.17 of the BP's estimates.

Next, in accordance with a standard literature reference on economic growth (Barro, 1991, 2003), we include the lagged growth of investment, the price level, the share of tertiary schooling, the 1/life expectancy at birth, the fertility rate, the ratio of government consumption to GDP, the openness ratio, the change in the terms of trade, and the *polity2* score as a measure of the institutional quality.[22] Model (3) in Table 3-2 lists the results for the full (nonmatched) sample for the years 1960-2009.[23] This specification reduces the Olympic hosting effects and the bidding effects.

Model (4) shows the results of a regression that both (a) controls for the usual determinants of economic growth and (b) restricts the sample to countries that match Olympic bidders/hosts. The combination of these two simple perturbations reduces all anticipated effects beyond significance. The variance explained by our model is tripled compared with BP.

[22] See www.systemicpeace.org/polityproject.html for details about the polity project.
[23] Because the World Bank data are available since 1960 only, and for a slightly different subset of countries, we again have a reduced sample size.

Table 3-2 News Shock and Anticipation Effects of Hosting and Bidding for the Olympic Games.

	Model (1)	Model (2)	Model (3)	Model (4)
L. Δ log (GDP)	0.0147	0.123	0.0166	0.115
	(0.0306)	(0.0661)	(0.0505)	(0.0799)
L. Δ log (government)	0.00494	0.0439	-0.0215	0.0158
	(0.0106)	(0.0345)	(0.0172)	(0.0419)
L. Δ log (investment)			0.00642	-0.0107
			(0.0101)	(0.0212)
L. Δ log (cpi)			0.0172	0.0343**
			(0.0131)	(0.0161)
Schooling			-0.0405	-0.0260
			(0.0207)	(0.0191)
1/Life expectancy			0.00243	2.035
			(2.004)	(3.492)
Fertility rate			-0.660	-0.953
			(1.186)	(1.061)
Openness ratio			-0.0208	0.0268
			(0.0231)	(0.0260)
Democracy			-0.0239	-0.114**
			(0.0471)	(0.0492)
Change in terms of trade			3.257	-3.429
			(2.242)	(1.843)
Bidding Country	0.291	-0.372	0.708	-0.439
	(0.562)	(0.665)	(0.681)	(0.719)
F.Bidding Country	-0.302	-0.155	-0.685	-0.241
	(0.481)	(0.469)	(0.786)	(0.806)
F2.Bidding Country	-0.522	-0.624	-0.911	-0.703
	(0.763)	(0.880)	(0.778)	(0.882)
F3.Bidding Country	0.776**	0.762	0.274	0.614
	(0.360)	(0.391)	(0.549)	(0.627)
F4.Bidding Country	0.238	0.159	0.421	0.0959
	(0.314)	(0.343)	(0.548)	(0.517)
F5.Bidding Country	-0.676	-0.804	-0.0747	-0.748
	(0.443)	(0.465)	(0.656)	(0.628)
F6.Bidding Country	0.603	0.106	0.623	0.165
	(0.598)	(0.658)	(0.990)	(0.955)
F7.Bidding Country	0.530	0.748**	0.267	0.233
	(0.351)	(0.319)	(0.554)	(0.526)
F8.Bidding Country	0.981***	0.576	1.439***	0.493
	(0.333)	(0.331)	(0.519)	(0.428)
F9.Bidding Country	0.417	0.792**	0.887	0.620
	(0.439)	(0.391)	(0.648)	(0.586)
F10.Bidding Country	-0.0720	-0.146	-0.217	-0.509
	(0.758)	(0.715)	(0.905)	(0.807)
Hosting Country	0.936	0.433	0.836	0.450
	(0.547)	(0.505)	(0.737)	(0.576)
F.Hosting Country	0.904	0.753	1.518	1.121
	(0.665)	(0.539)	(1.014)	(0.756)
F2.Hosting Country	1.839**	1.487	2.391	1.704
	(0.851)	(0.761)	(1.333)	(1.196)
F3.Hosting Country	1.731***	1.582***	1.241	0.831
	(0.366)	(0.368)	(0.717)	(0.655)
F4.Hosting Country	2.620***	2.197***	1.461	0.747
	(0.581)	(0.584)	(0.761)	(0.779)
F5.Hosting Country	1.443**	1.328**	1.118	0.799
	(0.638)	(0.521)	(1.169)	(0.628)
F6.Hosting Country	0.650	0.333	1.037	0.397
	(0.949)	(0.823)	(1.373)	(1.316)
F7.Hosting Country	-0.0441	0.143	0.201	0.470
	(0.485)	(0.516)	(0.539)	(0.641)
F8.Hosting Country	-0.379	-0.479	-1.336	-1.703

	(1.004)	(0.970)	(1.811)	(1.956)
F9.Hosting Country	0.329	0.298	0.381	0.129
	(0.350)	(0.308)	(0.543)	(0.520)
F10.Hosting Country	0.612	0.610	0.296	0.211
	(0.819)	(0.782)	(0.838)	(0.745)
Lagged government expenditure and GDP	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Barro	-	-	YES	YES
OECD only	-	-	-	-
PWT	7.0	7.0	7.0	7.0
Entropy balancing	-	-	-	-
Propensity score matching	-	YES	-	YES
R^2	0.170	0.320	0.264	0.433
AIC	41245.5	12957.8	16140.4	6288.2
Observations	5866	2159	2414	1106

Notes: Standard errors in parentheses are clustered on the country level in all models. AIC = Akaike Information Criterion, cpi = Consumer Price Index; FE = Fixed Effects; PWT = Penn World Table. ** p< 0.05, *** p < 0.01.

3.3 Robustness

To assess the robustness of our results, we evaluated various alternative specifications and sensitivity analyses. Model (5) in Table 3-3 presents the news shocks and anticipation effects when—instead of propensity score matching—the control group is restricted to Organisation for Economic Cooperation and Development (OECD) countries.

The matching approach inevitably leads to the exclusion of certain countries not comparable to the hosts and bidders, and therefore to a decline in sample size. The resulting increase in standard errors may reflect a variance-bias trade-off, that is, the coefficients are less biased at the cost of larger standard errors (Geman et al., 1992).

To assess the effect of the increase in standard errors because of reduced sample size, we employ entropy balancing as an additional approach to account for the structural differences between the treatment and control group. The procedure weights the observations in the control group, such that the moments (in our case, mean and variance) are similar to the moments of the treatment group (Hainmueller, 2012; Hainmueller and Xu, 2013). Because the weights are based on a set of pre-specified balance constraints, the resulting samples are balanced by design (Freier et al., 2015). There is no loss of observations when using this technique. Model (6) in Table 3-3 displays the results of a specification similar to Model (3) listed in Table 3-2.

Although as demonstrated in Table 3-1, the Olympic investment and government expenditures figures are relatively low, there may be concerns that these two covariables act as channels through which bidding for the Olympic Games affects GDP growth, in which case they could

not be included as covariables. To remedy such concerns, we exclude investment and government expenditures in Model (7), which is apart from that similar to Model (6).

We use the recently substantially revised PWT 8.1 data set as a further robustness check.[24] The PWT revision implies certain fundamental changes to selected data series. Appendix C Figure 3-1 illustrates these changes. Models (8) and (9) display the results of our Barro-augmented model with entropy balancing (Model 8) and propensity matching (Model 9). Both specifications fail to provide evidence for significant anticipation effects prior to the Olympic Games.

Finally, we use a set of alternative propensity score matching estimators, including a five nearest neighbor matching, radius matching, and kernel matching. The results are presented and explained in Appendix C Table 3-6.

None of the robustness checks suggests any significant news shock or anticipation effects of the Olympic Games.

[24] Feenstra et al. (2015) describe the new version of the Penn World Table for the 1950-2011 period and explain some of the differences between the data sets.

Table 3-3 Anticipation Effects of Hosting and Bidding for the Olympic Games: Robustness and Sensitivity Analysis.

	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)
L. Δ log (GDP)	0.297***	0.0774	0.154***	0.167**	0.184**
	(0.0778)	(0.0482)	(0.0532)	(0.0753)	(0.0740)
L. Δ log (government)	0.0359	-0.0176		-0.000261	-0.00218
	(0.0422)	(0.0341)		(0.0357)	(0.0334)
L. Δ log (investment)	-0.0387	0.0347**		0.0344	0.0152
	(0.0325)	(0.0142)		(0.0185)	(0.0208)
L. Δ log (cpi)	-0.0116***	0.0267	0.0353	0.0250	0.00407
	(0.00306)	(0.0242)	(0.0276)	(0.0341)	(0.0261)
Schooling	-0.00461	-0.00294	0.00360	-0.0367	0.000437
	(0.0244)	(0.0207)	(0.0176)	(0.0339)	(0.0245)
1/Life expectancy	-4.577	-3.093	-1.675	-6.010	-3.490
	(7.408)	(4.046)	(3.908)	(6.645)	(5.304)
Fertility rate	0.270	0.0640	0.501	0.924	-0.234
	(1.389)	(1.565)	(1.554)	(1.332)	(1.615)
Openness ratio	0.0594***	0.0565	0.0578	0.0237	0.0185
	(0.0180)	(0.0318)	(0.0329)	(0.0278)	(0.0241)
Democracy	-0.0606	-0.0987	-0.0919	-0.0362	-0.0489
	(0.0481)	(0.0831)	(0.0739)	(0.0481)	(0.0507)
Change in terms of trade	-4.755**	-1.801	-1.982	4.724	18.64***
	(2.221)	(4.453)	(4.515)	(3.148)	(3.342)
Bidding Country	0.693	0.642	0.159	-0.369	-0.305
	(0.348)	(0.535)	(0.707)	(0.943)	(0.986)
F.Bidding Country	-0.880	0.355	0.455	-0.319	-0.901
	(0.626)	(1.011)	(1.076)	(1.045)	(0.877)
F2.Bidding Country	0.285	-0.197	-0.375	-1.172	-1.643
	(0.478)	(0.664)	(0.915)	(1.029)	(1.152)
F3.Bidding Country	0.118	0.778	0.805	0.132	-0.162
	(0.381)	(0.609)	(0.641)	(0.657)	(0.721)
F4.Bidding Country	0.283	0.602	0.778	0.867	0.401
	(0.492)	(0.532)	(0.523)	(0.700)	(0.691)
F5.Bidding Country	-0.447	-0.630	-0.619	-0.945	-1.016
	(0.510)	(0.719)	(0.700)	(1.011)	(1.029)
F6.Bidding Country	-1.282	-0.651	-0.558	-0.821	-0.283
	(0.769)	(0.915)	(0.953)	(0.980)	(1.007)
F7.Bidding Country	0.126	0.122	0.331	-0.291	0.0871
	(0.472)	(0.545)	(0.523)	(0.474)	(0.479)
F8.Bidding Country	0.275	0.0584	0.102	0.0777	0.690
	(0.275)	(0.405)	(0.394)	(0.475)	(0.446)
F9.Bidding Country	0.410	0.385	0.444	0.290	0.289
	(0.482)	(0.578)	(0.545)	(0.729)	(0.693)
F10.Bidding Country	0.107	-0.538	-0.487	-0.801	-0.505
	(0.451)	(0.943)	(0.936)	(0.839)	(0.665)
Hosting Country	0.211	1.156	1.077	0.379	-0.308
	(0.541)	(0.649)	(0.646)	(0.897)	(0.791)
F.Hosting Country	0.594	1.301	1.234	0.772	0.000523
	(0.697)	(0.928)	(0.944)	(1.030)	(0.849)
F2.Hosting Country	0.909	1.503	1.618	1.542	1.502
	(1.238)	(0.911)	(0.928)	(1.030)	(1.091)
F3.Hosting Country	0.578	1.310	1.260	0.795	-0.123
	(0.645)	(0.675)	(0.684)	(0.670)	(0.959)
F4.Hosting Country	0.437	0.770	0.748	0.920	0.731
	(0.621)	(0.732)	(0.771)	(0.849)	(0.729)
F5.Hosting Country	0.779	0.642	0.661	0.283	0.275
	(0.447)	(0.603)	(0.610)	(0.780)	(0.687)
F6.Hosting Country	0.0371	0.516	0.452	0.349	0.125
	(0.965)	(1.021)	(1.018)	(1.092)	(1.285)
F7.Hosting Country	0.202	0.756	0.940	0.317	0.134
	(0.481)	(0.851)	(0.861)	(0.955)	(0.775)

F8.Hosting Country	-1.681	-1.895	-1.752	-2.152	-1.832
	(1.741)	(1.921)	(1.896)	(2.237)	(2.050)
F9.Hosting Country	-0.00142	0.316	0.239	-0.558	-0.740
	(0.322)	(0.638)	(0.568)	(1.039)	(0.984)
F10.Hosting Country	0.396	0.725	0.825	-0.286	-0.609
	(0.653)	(0.932)	(0.953)	(1.274)	(1.032)
Lagged government expenditure and GDP	YES	YES	-	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES
Barro	YES	YES	YES	YES	YES
PWT	7.0	7.0	7.0	8.1	8.1
OECD only	YES	-	-	-	-
Entropy balancing	-	YES	YES	YES	-
Propensity score matching	-	-	-	-	YES
R^2	0.529	0.505	0.498	0.388	0.320
AIC	3716.6	13682.8	13625.5	15029.4	6925.9
Observations	749	2414	2415	2545	1169

Notes: Standard errors in parentheses are clustered on the country level in all models. AIC = Akaike Information Criterion, cpi = Consumer Price Index; FE = Fixed Effects; PWT = Penn World Table. ** $p < 0.05$, *** $p < 0.01$.

3.4 Conclusion

The news shock theory implies that the news of an Olympic bid may change the agents´ plans and activities in the regional economy. Thus, economic effects may occur before the awarding of the Olympic Games to a city/nation or if a bid for the Olympic Games is not won. Because the hosting decision occurs seven years before the games and bid plans usually begin ten years before the games, the majority of earlier empirical studies may be biased because these studies did not allow for sufficient leads in the empirical implementation.

This article attempts to bridge the gap between a recent study (BP, 2015) that allows for ten yearly leads and lags (and finds significant economic effects) and earlier studies with fewer leads that did not find significant effects but did allow for structural models. In this study, we include both ten yearly leads and lags and structural models. We also compare the Olympic host nations with other matching nations. Converse to BP (2015), who find that a country's GDP growth rate—aggregated in a five-year window before hosting the games—can be raised by approximately 8.23 percentage points and that the cumulative effect up to seven years after the games adds approximately 15 percentage points, we do not find significant economic effects from the Olympic Games.

We conclude that BP's estimations are important because they indicate the possibility of news shocks and the anticipatory effects of the Olympic Games, which may come into effect early and may have been neglected by earlier studies that did not include enough leads. Nevertheless, the BP's results suffer both from a variable selection bias (by excluding the usual exogenous

variables of structural GDP models) and from a selection bias (by not using control groups that contain countries comparable to nations bidding for or hosting the Olympic Games).

On the basis of the BP's results, policy makers might be misguided to believe that organizing the Olympic Games is one of the most efficient approaches to fiscal spending, inducing multiplier effects of incomparable size. Their results risk that policy makers (and public opinion) will feel assured by beliefs brought forward by the usual ex ante "impact studies" on the Olympic Games, promising trillions of additional GDP, hundreds of thousands of additional jobs, a self-financing of the Olympic Games (secured by multiplier effects), and so on. Although there might be positive reasons to bid for the Olympic Games, our results provide a warning that the hopes for income effects should not be part of rational motivations.

3.5 Appendix C. Figures and Tables

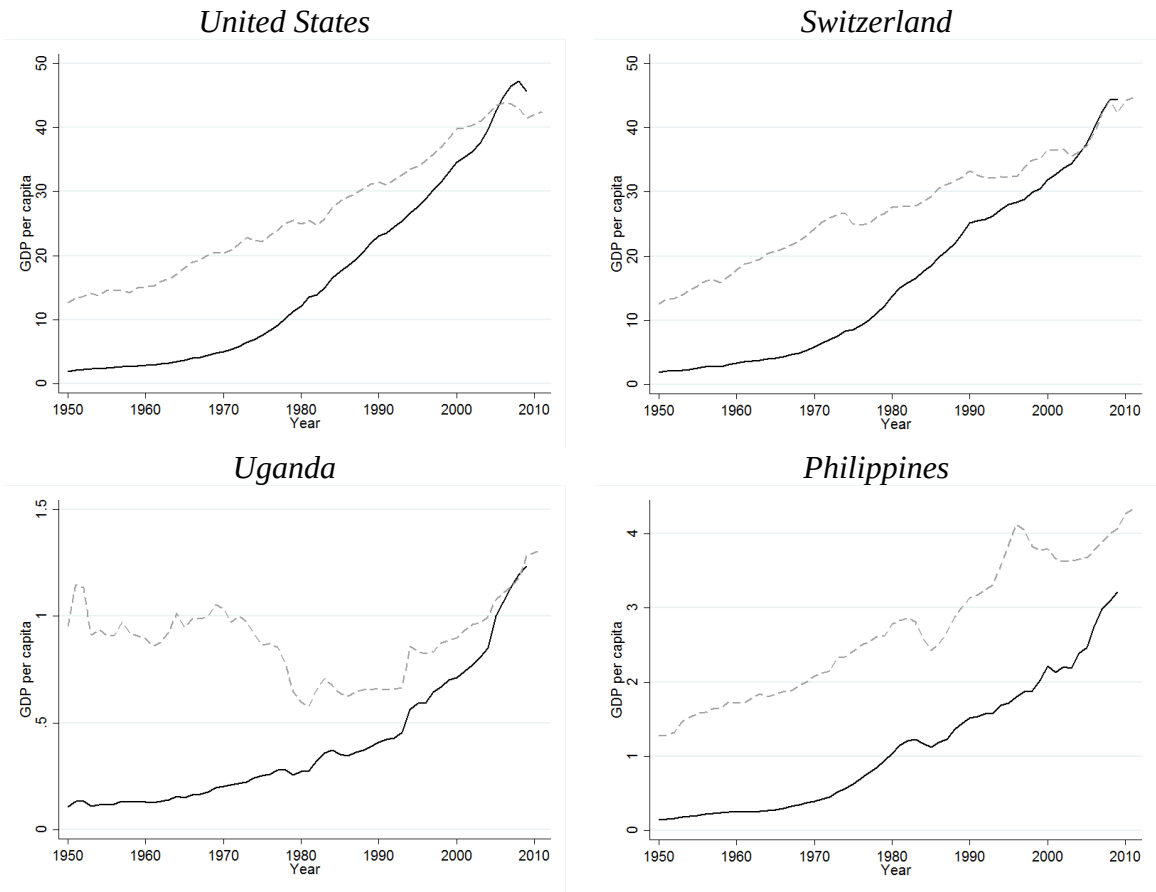

Figure 3-1 Comparison of Data: Penn World Table 7.0 versus Penn World Table 8.1.

Notes: Illustration of differences between PWT 7.0 and PWT 8.1 for data on GDP per capita (in millions US$) using the examples of the United States, Switzerland, Uganda, and the Philippines. Solid lines denote baseline data PWT 7.0, and dashed lines denote revised data PWT 8.1.

Table 3-4 Descriptive Statistics of Key Economic Variables.

Variable	Sample	Mean Treated	Control	Standardized Bias (%)	Percentage of Reduction in Abs. Bias
GDP	Unmatched	1948.90	597.34	137.4	
	Matched	1948.90	1266.50	69.4	49.5
Government Expenditures	Unmatched	193.18	57.29	121.9	
	Matched	193.18	117.20	68.2	44.1
Investment	Unmatched	466.93	155.34	115.8	
	Matched	466.93	317.72	55.5	52.1
Consumption	Unmatched	1300.20	403.00	139.5	
	Matched	1300.20	866.42	67.4	51.7
Population	Unmatched	60318.00	9811.30	47.0	
	Matched	60318.00	27995.00	34.6	26.5

Notes: The propensity scores are computed using one to one nearest neighbor matching. The standardized bias is computed as the difference between the subsample means, that is, the percentage difference of the square root of the average of the sample variances in the treated and control groups (Leuven and Sianesi, 2003; Rosenbaum and Rubin, 1985).

Table 3-5 Countries Included in the Subsamples.

Countries	Hosts	Bidders	OECD	PSM
Afghanistan	-	-	-	-
Albania	-	-	-	-
Algeria	-	-	-	-
Angola	-	-	-	-
Antigua and Barbuda	-	-	-	-
Argentina	-	X	-	X
Armenia	-	-	-	-
Australia	X	X	X	X
Austria	X	X	X	X
Azerbaijan	-	-	-	-
Bahamas	-	-	-	-
Bahrain	-	-	-	-
Bangladesh	-	-	-	-
Barbados	-	-	-	X
Belarus	-	-	-	-
Belgium	-	X	X	X
Belize	-	-	-	-
Benin	-	-	-	-
Bermuda	-	-	-	-
Bhutan	-	-	-	-
Bolivia	-	-	-	X
Bosnia and Herzegovina	X	-	-	X
Botswana	-	-	-	-
Brazil	-	-	-	X
Brunei	-	-	-	-
Bulgaria	-	X	-	X
Burkina Faso	-	-	-	-
Burundi	-	-	-	-
Cambodia	-	-	-	-
Cameroon	-	-	-	-
Canada	X	X	X	X
Cape Verde	-	-	-	-
Central African Rep.	-	-	-	-
Chad	-	-	-	-
Chile	-	-	X	-
China	X	-	-	X
Colombia	-	-	-	-
Comoros	-	-	-	-
Congo, Dem. Rep.	-	-	-	-
Congo, Republic of	-	-	-	-
Costa Rica	-	-	-	X
Cote d`Ivoire	-	-	-	-
Croatia	-	-	-	-
Cuba	-	X	-	X
Cyprus	-	-	-	-
Czech Republic	-	-	X	-
Denmark	-	-	X	X
Djibouti	-	-	-	-
Dominica	-	-	-	-
Dominican Republic	-	-	-	-
Ecuador	-	-	-	X
Egypt	-	X	-	X
El Salvador	-	-	-	X
Equatorial Guinea	-	-	-	-
Eritrea	-	-	-	-
Estonia	-	-	X	-
Ethiopia	-	-	-	-
Fiji	-	-	-	-
Finland	X	X	X	X

France	X	X	X	X
Gabon	-	-	-	-
Gambia, The	-	-	-	-
Georgia	-	-	-	-
Germany	X	X	X	X
Ghana	-	-	-	-
Greece	X	X	X	X
Grenada	-	-	-	-
Guatemala	-	-	-	X
Guinea	-	-	-	-
Guinea-Bissau	-	-	-	-
Guyana	-	-	-	-
Haiti	-	-	-	-
Honduras	-	-	-	-
Hungary	-	X	X	X
Iceland	-	-	X	X
India	-	-	-	X
Indonesia	-	-	-	-
Iran	-	-	-	-
Iraq	-	-	-	-
Ireland	-	-	X	X
Israel	-	-	X	X
Italy	X	X	X	X
Jamaica	-	-	-	X
Japan	X	X	X	X
Jordan	-	-	-	X
Kazakhstan	-	-	-	-
Kenya	-	-	-	X
Kiribati	-	-	-	-
Korea, Republic of	X	-	X	X
Kuwait	-	-	-	-
Kyrgyzstan	-	-	-	-
Laos	-	-	-	-
Latvia	-	-	X	-
Lebanon	-	-	-	-
Lesotho	-	-	-	-
Liberia	-	-	-	-
Libya	-	-	-	-
Lithuania	-	-	-	-
Luxembourg	-	-	X	X
Macao	-	-	-	-
Macedonia	-	-	-	-
Madagascar	-	-	-	-
Malawi	-	-	-	-
Malaysia	-	X	-	X
Maldives	-	-	-	-
Mali	-	-	-	-
Malta	-	-	-	-
Marshall Islands	-	-	-	-
Mauritania	-	-	-	-
Mauritius	-	-	-	-
Mexico	X	X	X	X
Micronesia, Fed. Sts.	-	-	-	-
Moldova	-	-	-	-
Mongolia	-	-	-	-
Montenegro	-	-	-	-
Morocco	-	-	-	-
Mozambique	-	-	-	-
Namibia	-	-	-	X
Nepal	-	-	-	-
Netherlands	-	X	X	X
New Zealand	-	-	X	X

Nicaragua	-	-	-	-
Niger	-	-	-	-
Nigeria	-	-	-	X
Norway	X	X	X	X
Oman	-	-	-	-
Pakistan	-	-	-	-
Palau	-	-	-	-
Panama	-	-	-	-
Papua New Guinea	-	-	-	-
Paraguay	-	-	-	-
Peru	-	-	-	-
Philippines	-	-	-	-
Poland	-	X	X	X
Portugal	-	-	X	X
Puerto Rico	-	-	-	X
Qatar	-	-	-	-
Romania	-	-	-	-
Russia	X	X	-	X
Rwanda	-	-	-	-
Samoa	-	-	-	-
Sao Tome and Principe	-	-	-	-
Saudi Arabia	-	-	-	-
Senegal	-	-	-	-
Serbia	-	-	-	-
Seychelles	-	-	-	X
Sierra Leone	-	-	-	-
Singapore	-	-	-	-
Slovak Republic	-	X	X	X
Slovenia	-	-	X	-
Solomon Islands	-	-	-	-
Somalia	-	-	-	-
South Africa	-	X	-	X
Spain	X	X	X	X
Sri Lanka	-	-	-	-
St. Kitts & Nevis	-	-	-	-
St. Lucia	-	-	-	-
St.Vincent & Grenad.	-	-	-	-
Sudan	-	-	-	-
Suriname	-	-	-	-
Swaziland	-	-	-	-
Sweden	-	X	X	X
Switzerland	-	X	X	X
Syria	-	-	-	X
Tajikistan	-	-	-	-
Tanzania	-	-	-	-
Thailand	-	X	-	X
Timor-Leste	-	-	-	-
Togo	-	-	-	-
Tonga	-	-	-	-
Trinidad &Tobago	-	-	-	-
Tunisia	-	-	-	-
Turkey	-	X	X	X
Turkmenistan	-	-	-	-
Uganda	-	-	-	-
Ukraine	-	-	-	-
United Arab Emirates	-	-	-	-
United Kingdom	-	X	X	X
United States	X	X	X	X
Uruguay	-	-	-	X
Uzbekistan	-	-	-	-
Vanuatu	-	-	-	-
Venezuela	-	-	-	X

Vietnam	-	-	-	-
Yemen	-	-	-	-
Zambia	-	-	-	-
Zimbabwe	-	-	-	-
187	17	30	35	58

Notes: The propensity score matching (PSM) column displays the sample generated by the propensity score matching procedure, including all hosts and bidders (the treatment group).

Table 3-6 News Shock and Anticipation Effects of the Olympic Games: Alternative Matching Estimators.

	Model (10)	Model (11)	Model (12)	Model (13)	Model (14)
L.dlgdp2	0.115	0.0774	0.0823	0.0501	0.0415
	(0.0799)	(0.0482)	(0.0615)	(0.0444)	(0.0410)
L.dlgov2	0.0158	-0.0176	-0.0284	-0.0119	-0.0105
	(0.0419)	(0.0341)	(0.0224)	(0.0201)	(0.0189)
L.dlinv2	-0.0107	0.0347**	0.00118	0.00857	0.0130
	(0.0212)	(0.0142)	(0.0162)	(0.0128)	(0.0116)
L.dlcpi2	0.0343**	0.0267	0.00378	0.0105	0.00988
	(0.0161)	(0.0242)	(0.0128)	(0.0113)	(0.0107)
Schooling	-0.0260	-0.00294	-0.0171	-0.0130	-0.0185
	(0.0191)	(0.0207)	(0.0175)	(0.0142)	(0.0135)
1/life expectancy	2.035	-3.093	0.393	-1.652	-0.571
	(3.492)	(4.046)	(2.943)	(2.145)	(1.844)
Fertility	-0.953	0.0640	-1.081	-0.240	-0.444
	(1.061)	(1.565)	(0.933)	(0.870)	(0.808)
Openness	0.0268	0.0565	0.0106	0.0285	0.0220
	(0.0260)	(0.0318)	(0.0169)	(0.0153)	(0.0144)
Democracy	-0.114**	-0.0987	-0.0966**	-0.0909**	-0.0918***
	(0.0492)	(0.0831)	(0.0420)	(0.0367)	(0.0349)
Change ToT	-3.429	-1.801	-3.908	-3.558	-2.650
	(1.843)	(4.453)	(2.236)	(1.944)	(2.075)
Bidding Country	-0.439	0.642	0.343	0.304	0.399
	(0.719)	(0.535)	(0.544)	(0.536)	(0.528)
F.Bidding Country	-0.241	0.355	-0.270	-0.301	-0.390
	(0.806)	(1.011)	(0.696)	(0.683)	(0.669)
F2.Bidding Country	-0.703	-0.197	-0.592	-0.629	-0.639
	(0.882)	(0.664)	(0.784)	(0.772)	(0.743)
F3.Bidding Country	0.614	0.778	0.616	0.591	0.538
	(0.627)	(0.609)	(0.600)	(0.512)	(0.508)
F4.Bidding Country	0.0959	0.602	0.0583	0.0489	0.0941
	(0.517)	(0.532)	(0.526)	(0.501)	(0.493)
F5.Bidding Country	-0.748	-0.630	-0.498	-0.414	-0.444
	(0.628)	(0.719)	(0.577)	(0.555)	(0.566)
F6.Bidding Country	0.165	-0.651	-0.129	0.0738	0.116
	(0.955)	(0.915)	(0.895)	(0.874)	(0.876)
F7.Bidding Country	0.233	0.122	0.360	0.319	0.262
	(0.526)	(0.545)	(0.454)	(0.436)	(0.443)
F8.Bidding Country	0.493	0.0584	0.472	0.581	0.669
	(0.428)	(0.405)	(0.405)	(0.388)	(0.390)
F9.Bidding Country	0.620	0.385	0.716	0.616	0.594
	(0.586)	(0.578)	(0.527)	(0.479)	(0.473)
F10.Bidding Country	-0.509	-0.538	-0.636	-0.620	-0.605
	(0.807)	(0.943)	(0.764)	(0.761)	(0.769)
Hosting Country	0.450	1.156	0.505	0.673	0.693
	(0.576)	(0.649)	(0.513)	(0.480)	(0.488)
F.Hosting Country	1.121	1.301	1.174	1.287	1.249
	(0.756)	(0.928)	(0.770)	(0.769)	(0.770)
F2.Hosting Country	1.704	1.503	1.530	1.683	1.736
	(1.196)	(0.911)	(1.031)	(1.069)	(1.051)
F3.Hosting Country	0.831	1.310	1.033	1.076	1.045
	(0.655)	(0.675)	(0.673)	(0.633)	(0.654)
F4.Hosting Country	0.747	0.770	0.608	0.766	0.839
	(0.779)	(0.732)	(0.789)	(0.725)	(0.702)
F5.Hosting Country	0.799	0.642	0.949	0.960	0.928
	(0.628)	(0.603)	(0.667)	(0.618)	(0.631)
F6.Hosting Country	0.397	0.516	0.405	0.519	0.547
	(1.316)	(1.021)	(1.154)	(1.175)	(1.175)
F7.Hosting Country	0.470	0.756	0.376	0.277	0.207
	(0.641)	(0.851)	(0.604)	(0.546)	(0.537)
F8.Hosting Country	-1.703	-1.895	-1.974	-1.821	-1.795

	(1.956)	(1.921)	(1.855)	(1.829)	(1.819)
F9.Hosting Country	0.129	0.316	0.100	0.185	0.141
	(0.520)	(0.638)	(0.492)	(0.411)	(0.414)
F10.Hosting Country	0.211	0.725	-0.0337	0.0865	0.0531
	(0.745)	(0.932)	(0.607)	(0.587)	(0.592)
Lagged government expenditures and GDP	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES
Barro	YES	YES	YES	YES	YES
OECD only	-	-	-	-	-
PWT	7.0	7.0	7.0	7.0	7.0
Entropy balancing	-	YES	-	-	-
Propensity score matching	YES	-	5NN	Radius	Kernel
R^2	0.433	0.505	0.453	0.409	0.379
AIC	6288.2	13682.8	8391.7	13196.1	13521.5
Observations	1106	2414	1495	2337	2342

Notes: As a reference, Model (10) corresponds to Model (4) of Table 3-2 and Model (11) corresponds to Model (6) of Table 3-3 in the main article. Instead of the default (Model (10)) matching estimator, which uses one to one nearest neighbor matching, the results of Models (12) to (14) are generated by alternative matching estimators: Model (12) matches each treatment observations to the five nearest neighbors. Model (13) uses radius matching with a caliper of 0.001. Each treatment observation is matched to all control observations within a 0.01 propensity score radius. Model (14) uses kernel matching with a biweight kernel and a bandwidth of 0.06. PWT = Penn World Table; ToT = Terms of trade. ** $p< 0.05$, *** $p < 0.01$.

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4 Prevention Effect of News Shocks in Anti-Doping Policies

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Abstract

This article contributes to the debate on anti-doping policies not by evaluating the policy itself but by evaluating the announcement of (new) policy measures. We develop a dynamic general equilibrium model for analyzing the effects of two different types of news shocks: (1) the announcement of improved drug testing technological opportunities and (2) the announcement of future increases in financial sanctions in case of detected anti-doping rule violations. We find that the anticipation of policy changes affects the behavior of potentially delinquent athletes. In both scenarios, our simulations show reduced drug abuse among athletes. We conclude that authorities may consider news shocks as an anti-doping strategy.

JEL classification: C61, D90, K42, L83, Z28

Keywords: Economics of crime, News shock in law, doping intensity, anticipated doping prevention

4.1 Introduction

Becker (1968) and Ehrlich (1973) modeled delinquency as a rational choice of individuals weighing their delinquent and nondelinquent alternative activities, considering the probability of being apprehended for a criminal offence and the severity of the punishment, comparing the expected returns from each alternative and then allocating their available time between both illegal and legal activities. Their contribution initiated numerous literatures that empirically seek to find the determinants of criminal behavior such as income inequality (Fajnzylber et al., 2002; Freeman, 1999), education (Lochner, 2004; Machin et al., 2011), unemployment (Phillips et al., 1972; Raphael and Winter-Ebmer, 2001), or socioeconomic factors (Saridakis, 2004). In the field of youth crime, Sickles and Williams (2008) show that an individual's choice to commit a crime substantially depends on one's personal stock of social capital. They assume that social capital accumulates through engaging in social networks, legitimate work, and marriage whereas the detection of criminal actions and time spent in prison reduces an individual's capital stock. The deterrent impact of increases in the probability and severity of punishment is analyzed by Cherry and List (2002), Ehrlich (1996), Garoupa (2001), Levitt (2002), Marvell and Moody (1994), Shadmehr and Bernhardt (2011), Freeman (1996), and Witte (1980). For an overview, see Benson and Zimmerman (2010).

This contribution adds to these findings by proposing a model that traces the impact dynamics of news shocks—also called anticipated shocks—on an individual's (potentially delinquent) behavior. We use the capital formation process proposed by Sickles and Williams (2008) in order to disaggregate an athlete's stock into a "fairly" accumulated sporting capital (e.g., training effort) component and a sporting capital component accumulated through the use of prohibited performance-enhancing substances (PES)s. We extend the model of Kydland and Prescott (1982) and develop a news-driven microfounded model of aggregate delinquency in the tradition of Beaudry and Portier (2004) and Jaimovich and Rebelo (2009).

We analyze the deterrent effects of anticipated changes in the probability of detection (and conviction) on the occasion of an announced improvement of testing technologies. As a second news shock, we model the effects of an announcement of increased (financial) sanctions. Our simulation results show an immediate drop in aggregate expected delinquent behavior in response to news, well before the increased probability of detection or higher sanctions actually come into force. We conclude that announced changes in crime prevention may increase the benefits of the implementation of "real" changes by prolonging the effects into the presence of the announcement, thus increasing the efficiency of the policy.

Our study also contributes to other aspects in the literature. First, we add to the literature on news shocks. Cochrane (1994) analyzes "standard"—i.e., for the economy unforeseeable—technological and monetary shocks and was one of the first to find that none of these shocks is the main driver of economic fluctuations. Instead, he finds evidence that news shocks explain a substantial fraction of business cycle dynamics. Other studies on the role of news include Barsky and Sims (2011), Beaudry and Portier (2006), Davis (2007), Khan and Tsoukalas (2012), and Schmitt-Grohé and Uribe (2012).

Our study is also related to the literature on health economics, as reviewed in Chaloupka and Warner (2000) and Cawley and Ruhm (2011), that is concerned with the use and abuse of drugs. Becker and Murphy (1988) develop a general model of rational addiction. They show that even risky health behavior—such as drug taking, smoking, and drinking—can be explained within the utility-maximizing framework of rational choice theory. Several studies, such as Manski (2000), Christakis and Fowler (2007), Lundborg (2006) and Cohen-Cole and Fletcher (2008), have been influenced by this paper.

In analyzing the determinants of delinquent behavior such as doping, our study is also related to the literature that distinguishes between "subjective" utility maximization and other determinants of economic behavior that lead to suboptimal societal outcomes (Davidson and Suppes, 1956; Fishburn, 1973; Mehlkop and Graeff, 2010).

In addition, we add to the literature on doping and anti-doping policies. Doping, i.e., the use of PESs such as erythropoietin or anabolic steroids (WADA, 2018), has been declared a criminal offence in countries such as Australia (since 2006), France (since 2008), Italy (2000), Spain (2006), Sweden (2011), New Zealand (2006), the United States (2004), and the United Kingdom (1968) and is subject to fines, imprisonment for up to fourteen years (United Kingdom) or both.[25] We add to the literature, which analyses doping in the framework of rational decision theory (e.g., Maennig, 2002), within game-theoretic approaches (Berentsen, 2002; Breivik, 1992; Haugen, 2004; Kirstein, 2014; Petróczi and Haugen, 2012), within conceptual behavioral frameworks (Donovan et al., 2002; Johnson, 2012; Petróczi and Aidman, 2008), with agent-based models (Westmattelmann et al., 2014), with criminal deterrence models (Strelan and Boeckmann, 2006) or with questionnaires (Barkoukis et al., 2014; Lentillon-Kaestner and Ohl, 2011; Striegel et al., 2010). Note that Castillo and Comstock (2007), de Hon et al. (2015), and Ulrich et al. (2018) estimate true doping prevalence rates of up to 70% dependent on the method

[25] For country specific information on anti-doping legislation, see, e.g., United States Anabolic Steroid Control Act (2004), Crouch and Department for Digital, Culture, Media & Sport (2017), Australian Sports Anti-Doping Act (2006), New Zealand Anti-Doping Act (2006), and Houlihan and García (2012).

applied and type of sport. This result—and the cost intensity of the current doping system—indicates an ongoing inefficiency of current anti-doping policies (Maennig, 2014) that requires for additional analysis and additional countermeasures.

Finally, we add to the research on news shocks in sport economics, which to date focuses on the anticipated economic effects of mega sport events (Langer et al., 2018).

The remainder of this article is organized as follows. Section 4.2 presents the model framework and suggests relevant calibrations. Section 4.3 presents our simulation results. Concluding remarks are made in Section 4.4.

4.2 Model and Model Calibration

In this section, we develop a model to analyze the expected doping behavior in elite sports in the case of news shocks, i.e., unexpected announcements of future changes in anti-doping policy. Following the tradition of Kydland and Prescott (1982), King et al. (1988), and King and Rebelo (1999) who analyzed a representative household, a representative firm, and a social planner, we model the behavior of three agents:

- A representative professional elite athlete whose utility depends on athletic success (SUC) and leisure time. Athletic success depends, among others, on the undetected use of banned performance-enhancing substances (PESs).
- A representative sporting institution (e.g., federation, club, or team manager) that acts similar to an enterprise (Zech, 1981) by producing goods (i.e., winnings) by hiring workers (i.e., high-performance athletes) and by using a specific sporting production function. In the following, we use the term “managing sporting institution”.
- A sport governing body (e.g., anti-doping agency) that struggles for a clean, ethical, and doping-free sporting environment but has no direct control over the rate of dopers/the frequency of doping. A governing body may have a wide range instruments, starting from moral suasion, but our model concentrates on the improvement of the testing technology and/or an increase in financial sanctions in cases of doping delinquencies.

In the following, we develop our model by describing the behavior of all three agents in more detail.

4.2.1 Elite Athletes

Following Becker and Murphy (1988), Breivik (1992), Maennig (2002), McCann (2005), and Pitsch and Emrich (2012), we assume that elite athletes behave in a rational manner to reach

their personal goals and seek to maximize their expected utility. Furthermore, we suppose that athletes derive utility not only from nonpecuniary income sporting success (e.g., winning competitions and being popular) but also from pecuniary income (Ehrenberg and Bognanno, 1990; Becker and Huselid, 1992). The more an individual trains, the more successful she has, the more money she earns (prize money, starting premiums, money from endorsement deals, and performance-based stipends), and the more she can spend on consumption goods and theoretically spend on PESs.

Athletes allocate their available time between two activities: athletic activities and leisure. Athletic activities include time spent in both sports training and in competition. Utility is separated into the following: SUC and leisure. We assume habit formation to mean the following: professional athletes derive utility not only from the current level of SUC_t but also from the level of current SUC_t relative to past SUC_{t+k-1}. Put differently, an athlete becomes accustomed to a certain level of SUC and does not want to lose her last seasons' realized (worldwide) ranking (Hall and Foster, 1977; Mallett and Hanrahan, 2004; Spieker and Hinsz, 2004).

Considering these assumptions and following Abel (1990), Boldrin et al. (2001), and Campbell and Cochrane (1999), the log-utility function of the representative athlete living for an infinite number of periods (King and Rebelo, 1999) takes the form:

$$\begin{aligned} U_{t+k} &= E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}(SUC_{t+k}, 1 - N_{t+k}) \\ &= E_t \sum_{k=0}^{\infty} \beta^k \{\ln(SUC_{t+k} - \phi SUC_{t+k-1}) + \theta \ln(1 - N_{t+k})\} \end{aligned} \tag{4-1}$$

where $0 < \beta < 1$ is the discount factor that reflects an athlete's preference for current over future success-leisure bundles. The parameter $0 < \phi \leq 1$ measures the strength of the habit process with a high value of ϕ indicating strong habit formation. The limiting case $\phi = 0$ is the standard case of time-separable utility, i.e., the utility is not affected by habits. E_t is the rational expectations operator conditional on the information in period t, and SUC_t is the sporting success in period t. With the time endowment normalized to unity, the individual's leisure time is $1 - N_t$. Leisure is the time not devoted to professional sporting activities, i.e., sports training and competition. The parameter θ, where $\theta > 0$, indicates how leisure is valued relative to SUC.

The athlete starts each period $t = 0, 1, 2, ...$ with sporting capital S_{t-1} (Rowe, 2015) [26] in parallel to the conceptualization of human capital in the spirit of Becker (1964). More precisely, sporting capital is the stock of specialized athletic and high-level sport skills that accumulate over time. Sporting capital may increase or decrease over time. Sporting capital incorporates individuals' natural athletic talent, physical constitution, level of fitness and health, which may be increased via professional training by ameliorating their physical constitution—such as strength, speed, coordination and endurance—and their psychological constitution. Having a strong mindset and being mentally balanced improves sporting performance and helps athletes handle stress, setbacks and losses (see, among others, Gould et al., 2009; Gould and Maynard, 2009; Morgan, 1979). An elite athlete's level of sporting capital affects her probability of winning. The higher the capital stock, the better the athlete's performance, and the better the chance of winning. Ceteris paribus, without efficient training, sporting capital decreases, indicated by the parameter δ_{SC}, the natural sporting capital depreciation rate (e.g., physical and psychological deterioration).

Sickles and Williams (2008) call for a dynamic model of delinquency in which an individual's stock of social capital substantially plays a central role. We suggest sporting capital formation to take the functional form:

$$S_{t+k+1} = \pi S^1_{t+k+1} + (1-\pi) S^0_{t+k+1} \tag{4-2}$$

where

$$S^0_{t+k+1} = (1-\delta_{SC}) S_{t+k} + \gamma_{DE} S_{t+k} N_{t+k} + I_{t+k} \tag{4-3}$$

in case of undetected doping and

$$S^1_{t+k+1} = (1-\delta_{SC}) S_{t+k} - \gamma_{DH} S_{t+k} N_{t+k} + I_{t+k} \tag{4-4}$$

in case of detected doping.

S_t is the stock of sporting capital at the end of period t. π is the probability of doping detection. Thus, $(1-\pi)$ is the probability of undetected doping. Parameter γ_{DE} represents the doping efficiency (DE) and thus the power of the applied PES. Put differently, when illicit drug taking is undetected, it increases an athlete´s capital stock by the efficiency rate γ_{DE}. It has a positive effect on the athlete's performance and therefore her sporting success. By contrast, detected doping implies a decrease in an athlete's capital stock by rate γ_{DH}. The subscript of parameter γ_{DH} denotes doping harm (DH), including potential short-term or long-term fatal health

[26] Rowe (2015) extensively specifies the different kinds of concepts of sporting capital that can be found in the literature.

consequences such as cardiovascular complications and cancer (Birzniece, 2015; Tentori and Graziani, 2007) and social consequences such as the loss of reputation in case of detected use of PESs (Maennig, 2002; Kräkel, 2007).

An athlete maximizes utility subject to the steady state condition:

$$W_{t+k}N_{t+k} + R_{t+k}S_{t+k} = SUC_{t+k} + I_{t+k} + T_{t+k} \tag{4-5}$$

The representative athlete supplies her time N_t (for training and tournament) and her sporting capital stock S_t to the managing sporting institution and earns a wage rate W_t and capital rate R_t. Hence, W_t and R_t are the gains from professional training, sports contests and sporting capital. I_t is investment (e.g., in sporting capital), and T_t denotes lump sum payments including financial penalties in the case of detected and penalized doping. According to equation (4-5), expenses for SUC, investment, financial penalties and the purchase of PESs have to be covered by earnings from wages and sporting capital income.

An athlete's dynamic maximization problem can be expressed as an intertemporal Lagrangian $\mathcal{L}$:

$$\begin{aligned}\mathcal{L} = E_t\Bigg\{\sum_{k=0}^{\infty}\beta^k[\ln(SUC_{t+k} - \phi SUC_{t+k-1}) + \theta\ln(1 - N_{t+k})] \\ + \lambda_{t+k}(W_{t+k}N_{t+k} + R_{t+k}S_{t+k} - SUC_{t+k} - T_{t+k} - I_{t+k})\Bigg\}\end{aligned} \tag{4-6}$$

where λ_{t+k} is the Lagrangian multiplier associated with the steady state constraint equation (4-5).

Eliminating I_t in the steady state constraint (4-5) and inserting equations (4-3) and (4-4) in equation (4-2) yields:

$$\begin{aligned}\mathcal{L} = E_t\Bigg\{\sum_{k=0}^{\infty}\beta^k[\ln(SUC_{t+k} - \phi SUC_{t+k-1}) + \theta\ln(1 - N_{t+k})] \\ + \lambda_{t+k}(W_{t+k}N_{t+k} + R_{t+k}S_{t+k} + a^*S_{t+k} + (c^* - b^*)S_{t+k}N_{t+k} \\ - SUC_{t+k} - T_{t+k} - S_{t+k+1})\Bigg\}\end{aligned} \tag{4-7}$$

where $a^* = 1 - \delta_{SC}$, $b^* = \pi\delta_{DH}$, and $c^* = (1 - \pi)\delta_{DE}$. Partially differentiating equation (4-7), the first-order conditions with respect to SUC_t, N_t, S_{t+1} and λ_t are given by

$$\frac{\partial \mathcal{L}}{\partial SUC_t} = \frac{1}{SUC_t - \phi SUC_{t-1}} - \lambda_t - \beta\phi \frac{1}{SUC_{t+1} - \phi SUC_t} = 0 \Leftrightarrow$$

$$\lambda_t = \frac{1}{SUC_t - \phi SUC_{t-1}} - \beta\phi \frac{1}{SUC_{t+1} - \phi SUC_t} \tag{4-8}$$

Equation (4-8) defines the representative athlete's optimal SUC path for utility maximization. Because of habit formation, past and expected future SUC increases an athlete's current utility. Moreover, equation (4-8) depicts that PESs may have not only positive immediate effects but also permanent or at least long-lasting effects on an athlete's athletic performance (Egner et al., 2013; Sharples et al., 2016). The Lagrange multiplier λ_t reflects the marginal utility of SUC at time t.

Assuming that elite athletes have rational expectations based on all information available in period t about current and future wages W_t and sporting capital rates R_t, equation (4-9) derives the optimal labor supply, implying the optimal choice of leisure $(1 - N_t)$. The marginal rate of substitution between SUC and leisure equals the real wage.

$$\frac{\partial \mathcal{L}}{\partial N_t} = \frac{-\theta}{1 - N_t} + \lambda_t W_t = 0 \Leftrightarrow \frac{\theta}{1 - N_t} = \lambda_t (W_t + (c^* - b^*) S_t) \tag{4-9}$$

The marginal value of sporting capital is calculated as follows:

$$\frac{\partial \mathcal{L}}{\partial S_{t+1}} = -\lambda_t + \beta E_t[\lambda_{t+1}(R_{t+1} + a^* - b^* + c^*)] = 0 \Leftrightarrow$$

$$\lambda_t = \beta E_t[\lambda_{t+1}(R_{t+1} + a^* + (c^* - b^*) N_{t+1})] \tag{4-10}$$

Thus, the optimal value of sporting capital depends on its natural depreciation rate δ_{SC}; the probability of doping detection π; the positive and negative effects of PESs, δ_{DE} and δ_{DH}, respectively; and the training effort N_t.

The first-order efficiency condition (4-11) equals the rearranged steady state constraint: [27]

$$\frac{\partial \mathcal{L}}{\partial \lambda_t} = W_{t+k} N_{t+k} + R_{t+k} S_{t+k} + a^* S_{t+k} + (c^* - b^*) S_{t+k} N_{t+k} - SUC_{t+k} - T_{t+k} - S_{t+k+1} = 0 \tag{4-11}$$

4.2.2 The Managing Sporting Institution

The managing sporting institution develops and provides training programs. The programs teach athletes relevant skills, tactics, and techniques and encourage them (not exclusively) in

[27] See Appendix D for more details on the rearranged budget constraint.

tournaments or in matches. In doing so, the institution focuses on realizing athletes' full potential and enhancing their sporting performance. We assume that the managing sporting institution seeks to produce (team or individual athlete) wins. For this purpose, the use of production functions in the field of sports economics, also called success functions, has attracted considerable interest. Classical references include Scully (1974), Schofield (1988), and Zech (1981). Most studies model a production function in the context of a specific type of sport. Therefore, the output measure is often defined as team victories, winning percentage, points, etc. as a function of sports-specific playing inputs.[28] We define a general form of the Cobb-Douglas-type sporting production function—independent of the type of sport:

$$Y_{t+k} = S_{t+k}^{\alpha}(J_{t+k}N_{t+k})^{1-\alpha} \tag{4-12}$$

Y_t denotes the production of SUC (i.e., financial payoffs and winnings, respectively). As mentioned in Section 4.2.1, S_t represents the sporting capital stock (for example, physical constitution) owned by elite sportsmen. N_t is the amount of time spent in training and competition by the athlete. Exponent $1-\alpha$ reflects the effectiveness of managing sporting systems (Dawson et al., 2000). J_t denotes the aggregate doping culture/prevalence in a sport (Strulik, 2012).

The managing sporting system uses the labor input of the representative athlete and sporting capital to maximize its profit function:

$$\Gamma_{t+k} = S_{t+k}^{\alpha}(J_{t+k}N_{t+k})^{1-\alpha} - W_{t+k}N_{t+k} - R_{t+k}S_{t+k} \tag{4-13}$$

Equation (4-13) combines the sporting production function with the costs paid by the managing sporting system. In particular, the costs can be divided into an athlete's earnings/salary, W_tN_t, and sporting capital-related bonuses, R_tS_t (Robeck, 2015).

The first order conditions are as follows:

$$\frac{\partial\Gamma}{\partial S_t} = \alpha\left(\frac{J_tN_t}{S_t}\right)^{1-\alpha} - R_t = 0$$

which can be simplified to

$$R_t = \alpha\frac{Y_t}{S_t} \tag{4-14}$$

and

[28] For example, in his study of Major League Baseball, Zech (1981) includes hitting, running, defense, and pitching. According to Berri (1999), National Basketball Association teams' production of wins depends on numerous factors such like how a team acquires the ball, a team's ball handling, and a team's ability to convert possessions into points, just to name a few.

$$\frac{\partial \Gamma}{\partial N_t} = (1-\alpha)\left(\frac{S_t}{J_t N_t}\right)^{\alpha} J_t - W_t = 0$$

which can be simplified to

$$W_t = (1-\alpha)\frac{Y_t}{N_t} \tag{4-15}$$

Equation (4-14) denotes the demand of the managing sporting system for the representative athlete´s sporting capital. Equation (4-15) denotes the managing sporting system´s demand for labor of the athlete. Both equations have standard micro-type interpretations. The marginal products indicate that the price of a factor input (i.e., labor and sporting capital) is equal to the marginal productivity of the factors. In summary, the managing sporting institution is interested in high profits—e.g., due to good competition results—but also in low wages (Robeck, 2015).

4.2.3 Regularity System and Anti-Doping Agency

The third part of the model consists of the anti-doping bodies' decision making (for example, the World Anti-Doping Agency (WADA) and National Anti-Doping Agencies (NADAs)). We will study two anti-doping policy actions/scenarios: first, improved testing technology; and second, an increase in financial sanctions in cases of detected doping delinquencies.

The permanent use of an improved testing technology (or higher testing frequencies) leads to an increased detection rate of doped elite athletes. We assume that the aggregate doping prevalence, J_{t+k}, is given by

$$J_{t+k} = [(1-\delta_\Omega)\Omega + \delta_\Omega J_{t+k-1}](1-i_{t+k}) \tag{4-16}$$

Let us assume that doping is either directly observable at the team level or that athletes exchange knowledge about doping activities. Therefore, Ω denotes the estimated dark figure of dopers. δ_Ω is "the rate at which the doping history of the sport is depreciated in the backward-looking mind of athletes" (Strulik, 2012, p. 548). i_t is the result of the testing activities of the anti-doping bodies with

$$i_t = \pi + v_t \tag{4-17}$$

and

$$v_t = \rho_v v_{t-1} + \varepsilon_{t-q}^{v} \tag{4-18}$$

where π represents the official average doping detection rate before the authority changes its anti-doping policy, and v_t represents a favorable anti-doping policy (technology) shock with persistence parameter $\rho_v \in [0,1]$.

Since we consider anticipated shocks, also called news shocks, ε_{t-q}^{v} is the effect of the announcement of new and enhanced testing technologies to the elite athletes q periods ahead before the shock actually occurs. Therefore, letter q represents the anticipation horizon of a news shock. For example, in the case $q = 3$, athletes learn about the anti-doping authority's intended use of better testing methods three periods ahead. In the case $q = 0$, anti-doping policy changes are unforeseeable for athletes.

Closing the model, we assume an authority's resource constraint:

$$T_{t+k} = G_{t+k} \tag{4-19}$$

The anti-doping authority collects fines T_t from all detected doped athletes. In turn, these revenues are used to finance law enforcement expenditures G_t.

In general, once an athlete is found guilty of doping, this leads to a disqualification from a game, an instant forfeiture of prizes (i.e., medals, trophy money, and points), and a (temporary) suspension from participating in any other sports competitions for some length of time ("World Anti-Doping Code", 2014). In some rare instances, anti-doping organizations/authorities usually impose additional monetary penalty payments. Several studies (e.g., Berentsen, 2002; Huybers and Mazanov, 2012; Maennig, 2002; Maennig, 2009; McNamee and Tarasti, 2010; Westmattelmann et al., 2018) discuss the implementation of (increased) financial penalties in order to punish athletes convicted of doping. Following these studies, we consider this instrument as a second anti-doping policy strategy and assume the following autoregressive first-order process:

$$G_t = \rho_g g_{t-1} + \varepsilon_{t-q}^{g} \tag{4-20}$$

where $\rho_g \in [0,1]$, and $\varepsilon_t^g \sim iidN(0,1)$.

4.2.4 Model Calibration

In the subsequent numerical model simulations, we use calibrations, as summarized in Table 4-1. We set the discount factor $\beta = 0.99$, which is a commonly selected value in the economics literature (King et al., 1988). Following Dawson et al. (2000), we set the scale parameter in the sporting production function/the efficiency of the managing sporting institution (equation (4-12)), $1 - \alpha = 0.823$.

For habit formation, we draw on the estimated parametrization of Havranek et al. (2017). For computational reasons, the potential value of the habit parameter, ϕ, is restricted and has to be smaller than one. If ϕ is exactly one, the marginal utility in the steady state converges to infinity.

High values of ϕ indicate strong habits. In other words, current utility substantially depends on the history of past SUC. For our analyses, we alternatively set $\phi = 0.3, 0.5, 0.99$.

Anti-doping agencies such as the WADA publish yearly official detection rates of 1–2% (WADA, 2016; de Hon et al., 2015). We set the average doping detection rate to π =0.015, denoting that 1.5% of all tested athletes were convicted PES abusers. In reality, doping tests are imperfect and fail to detect all cheaters (de Hon et al., 2015; Maennig, 2014). Consequently, not every athlete who uses a PES is detected as a doper.

To bridge the gap between the share of doped athletes and the share of doped and detected athletes, we include parameter Ω as an additional measure of the share of drug use among elite athletes (as, for example, in Westmattelmann et al., 2014) and repeat our model simulations considering different values. Depending on the sport, the definition of doping and the method applied, the estimated prevalence of PES use lies between 3% and 71% (Castillo and Comstock, 2007; de Hon et al., 2015; Ulrich et al., 2018). To provide comprehensive analysis, we assume alternative real doping rates among professional athletes of 0.03/0.1/0.7.

We assume that athletes who have been convicted of doping will not use PESs again in the next period. Therefore, parameter δ_{Ω} denotes the depreciation rate of the estimated share of drug takers and equals the official doping detection rate π.

Parameter δ_{SC} denotes the depreciation rate of sporting capital—and thus the change of athletic performance—in case of training inactivity. García-Pallarés et al. (2009) investigate the physiological parameters, hormonal markers and kayaking performance of top-level paddlers and observe a significant mean decline of 7.9% in athletic performance following five weeks of complete training cessation. More recently, Maldonado-Martín et al. (2017) analyze the body composition and hematological and physiological parameters of highly trained young cyclists. They find a mean decrease of sporting performance of 6.5% $\pm$3.1% (mean $\pm$ standard deviation) in response to five weeks of stopped training. Based on these aforementioned studies, we assume a sporting capital depreciation rate of 10%, i.e., $\delta_{SC} = 0.10$, as our time period is one quarter (approximately twelve weeks).

Furthermore, an elite athlete's sporting capital may be affected by the use of PESs. If doping is undetected, it is effective and increases an athlete´s sporting capital stock, resulting in higher sport performance. Medical studies measure the short-run physiological effects of PESs. Boyce (2003), Barbalho and Barreiros (2015), and Hartgens and Kuipers (2004) find a 5-20% increase in muscle growth and strength, a 2-5kg increase in body mass, and a 3-9% increase in aerobic capacity. To our knowledge, there are no estimates of the effects of PESs on an elite-level

athlete's performance, but we use the aforementioned findings as proxies for alternative calibrations of undetected doping increases on an athlete's performance (δ_{DE}) of 2%/8%/15%. By contrast, if a doping athlete is detected as a cheater, their capital stock declines by a factor of $\delta_{DH} = -0.5$.

Next, according to Maennig (2014) and WADA (2018), only 4.0% of the overall WADA budget is used for doping tests.[29] For this purpose, parameter $\bar{G}$ equals -3.0116 to match this ratio in the steady state in our simulations.[30]

Table 4-1 Model Parameters.

Parameter	Value	Description
β	0.99	Discount factor
α	0.177	Exponent of the sporting production function
ϕ	[0; 1]	Habit persistence parameter
π	0.015	Doping detection rate
δ_{SC}	0.1	Sporting capital depreciation rate
δ_{Ω}	0.015	Depreciation rate of Ω
Ω	0.03, 0.1, 0.7	Share of drug-using athletes
γ_{DE}	0.02, 0.08, 0.15	Effectiveness of PESs
γ_{DH}	-0.5	Harm of PESs
$\bar{G}$	-3.0116	WADAs capital ratio for doping tests
ρ_v	[0; 1]	Shock persistence
ρ_g	[0; 1]	Shock persistence
q	0, 3, 8	Anticipation horizon of the shock

Using these parametrizations, we compute time series for the aggregate doping behavior, training effort, sporting capital, and SUC. We use the logs of each equation, linearizing them around the balanced growth path, in order to investigate percentage deviations from the trend. Appendix E provides a complete summary of the log-linearized model.

[29] The largest elements of WADA's operating expenditures in 2014 are (i) salaries and other personnel costs, (ii) research grants, and (iii) travel and accommodation costs (WADA, 2018; WADA, 2014).
[30] For numerical simulations, we solve the nonstochastic steady state as follows: $\bar{G} \equiv G_t = e^{\bar{g}}$.

4.3 Results - Doping in the Case of News Shocks of Anti-Doping Measures

First, we explore an anticipated technology shock. Second, we discuss an anticipated sanction policy shock.

4.3.1 Improved Drug Detection of Elite Athletes

Figure 4-1 shows the estimated impulse responses to an anticipated improved anti-doping testing technology that increases the detection rate by 1%. The impulse responses depict the three typical temporally different stages induced by news shocks. The first is the preimplementation dynamics (indicating anticipation effects) during the anticipation horizon q, which is the time span between the announcement and the realization of news shock. The second is the implementation period (indicating realization effects) itself. The third is the postimplementation dynamics (indicating long-term realization and adjustment effects) beginning one period after the materialization of news shocks (Schmitt-Grohé and Uribe, 2012; Mertens and Ravn, 2011). Before t=0, the sporting system is in a steady state in the sense that all agents have fully adapted to the prevailing data set. In t=0, the anti-doping authority announces the application of better drug testing technologies starting in t=3 (t=8), i.e., three (or eight) quarters ahead, before it actually implements it. During the anticipation horizon, the doping intensity among elite athletes decreases instantly, but only to a minor extent. According to the habit formation denoted by equation (4-8), athletes want to maintain their attained level of SUC. The news shock thus induces athletes to spend more time on sports (i.e., training effort N_t increases), immediately starting with the announcement, and further increasing over time. According to equation (4-3), this implies an increase in sporting capital S_t and SUC_t. Training effort, sporting capital and SUC peak in period two (seven), i.e., one period before the anticipated shock materializes.

The implementation in period three (eight) leads to a further reduction in the use of PESs. Moreover, the training effort partly decreases but does not return to before-announcement. The sporting capital stops increasing and converges to its new, increased steady state value. In response to the decreased training effort, sporting success SUC drops.

In the long-run postimplementation periods, the doping intensity is decreased by approximately 0.45%. The training effort and the SUC re-increase slightly after the drop due to the materialization of the shock and converge to their new overall increased steady state levels. Compared to the response of the training effort, SUC reacts more moderately. The impulse responses of the training effort and the sporting capital can be explained by the long-lasting beneficial effects of PESs in the human body (Egner et al., 2013). Positive effects of prohibited drugs combined with an increased training effort initially in the preimplementation period of new tests lead to

increased sporting capital and increased SUC. After the implementation of the new tests, training efforts decline by approximately 1% whereas the sporting capital remains almost unchanged due to the beneficial long-lasting effects of doping.

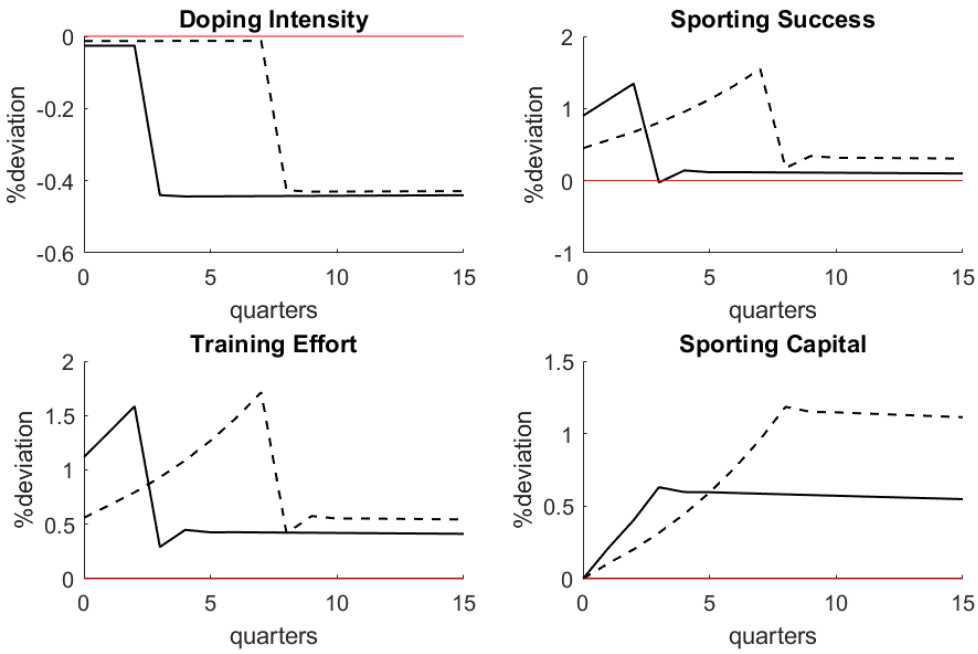

Figure 4-1 Impulse Responses to an Anticipated Improved Doping Test Technology.

Notes: The vertical axes show the percentage deviations from the steady state. The horizontal axes show the anticipation horizon q. The time unit is one quarter. The solid black lines are the response of a three period in advance announced shock. The dashed lines are the responses to an eight period ahead announced news shock. We set $\Omega = 0.10$, $\phi = 0.50$, $\delta_{DE} = 0.08$, and $\rho_v = 0.999$.

Table 4-2 provides the relative variances (σ_f^2) and standard deviations (SDs) of the doping intensity for different values of the overall doping rate (Ω) and the habit persistence parameter (ϕ). The relative variance measures the deviation from the initial steady state value. The results show several important things.

First, the lower the doping rate Ω is, the lower the deviation from the initial steady state level due to news shocks. Second, for low (3%) and moderate (10%) doping rates, the sooner technology news shocks arrive at the sporting system (i.e., the larger q is), the larger the first reaction during the anticipation period, and a large share of PES using athletes decrease or totally stop their use of PESs. Consequently, the relative variances σ_f^2 and the SD of doping behavior are an increasing function of the anticipation horizon q. Third, for large unreported shares of drug takers *($\Omega \geq 70\%$)*, the opposite is true: the relative variances σ_f^2 and the SD of doping

behavior decrease as q increases. In other words, in case of large shares of athletes who doped undetected in the past, more athletes continue doping, despite the announced news.

Table 4-2 Relative Variances and Standard Deviations of Doping Behavior in Response to a Permanent (Un)Anticipated Technology Shock.

		$\Omega = 0.03$			$\Omega = 0.10$			$\Omega = 0.70$		
		$q = 0$	$q = 3$	$q = 8$	$q = 0$	$q = 3$	$q = 8$	$q = 0$	$q = 3$	$q = 8$
$\phi = 0.33$	σ_f^2	3.141	3.238	3.452	11.917	12.085	12.655	17.523	16.468	16.025
	SD	1.772	1.800	1.858	3.452	3.476	3.557	4.186	4.058	4.003
$\phi = 0.50$	σ_f^2	3.787	3.900	4.153	11.147	11.322	11.879	15.355	14.598	14.382
	SD	1.946	1.975	2.038	3.339	3.365	3.447	3.919	3.821	3.792
$\phi = 0.99$	σ_f^2	7.917	8.138	8.650	8.356	8.583	9.112	11.291	11.164	10.318
	SD	2.814	2.853	2.941	2.891	2.930	3.019	3.360	3.341	3.212

Notes: The table reports the relative variance of doping behavior σ_f^2 and the standard deviation (SD) in response to a permanent (un)anticipated positive anti-doping technology shock in the case of a low ($\Omega = 0.03$), moderate ($\Omega = 0.10$) and high ($\Omega = 0.70$) unreported/unofficial share of drug abuse among elite athletes. Parameter ϕ denotes the level of habit formation. Parameter δ_{DE} is set to 0.08, and the shock persistence ρ_v is set to 0.999.

4.3.2 Deterrent Effects of a Penalty Shock

This subsection documents the impulse responses to an anticipated positive anti-doping sanction shock, i.e., increasing financial penalties by 1%. The dynamics are found to be similar to those in response to technology news.

In Figure 4-2, the doping intensity displays a slight downturn immediately after the announcement of rising financial penalties for doping offenses. Athletes instantaneously compensate for their (future) reduced use of PESs by extending their training effort. Thus, training effort, sporting capital and SUC increase and peak in one quarter before the implementation of the new policy.

In the realization period of quarter three (eight), the doping intensity among athletes decreases again and reaches a new steady state level. Training effort and sporting capital also decrease in response to the shock but stay above their initial steady state values.

In the postimplementation periods, the use of prohibited PESs decreases by approximately 0.13%. The training effort slightly re-increases and converges to a new increased steady state level, as does the SUC. Compared to technology news shocks, athletes react only marginally in the case of monetary sanction news. This finding is in line with Grogger (1991).

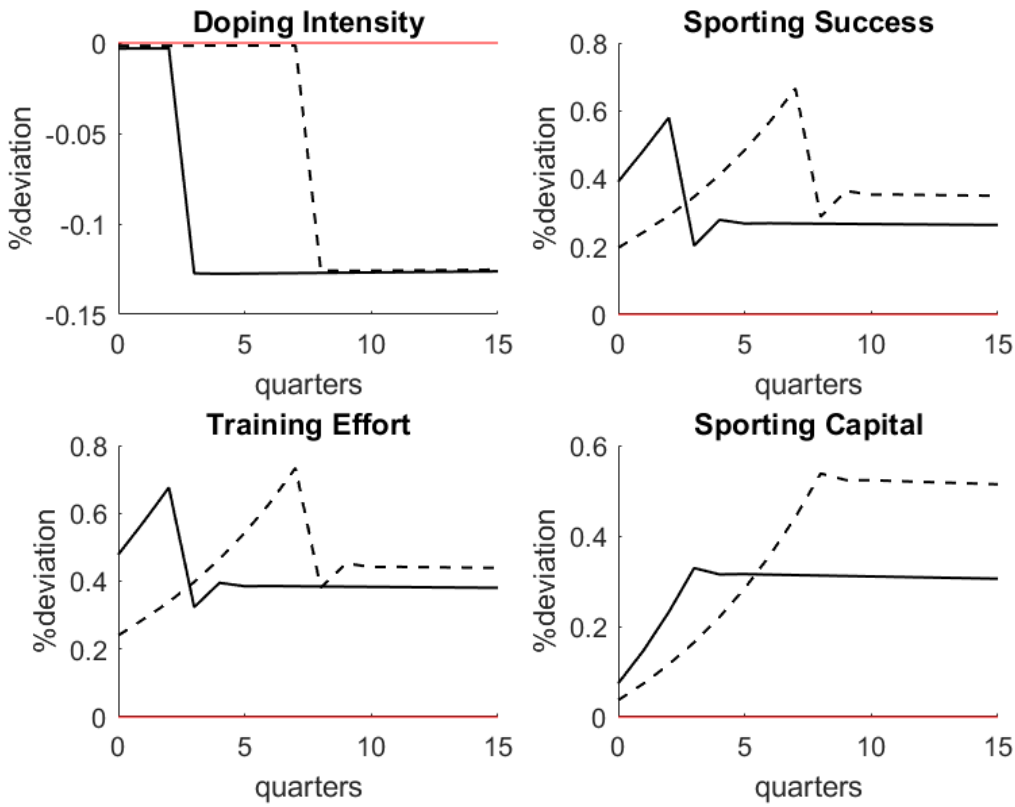

Figure 4-2 Impulse Responses to an Anticipated Permanent Sanction Shock.

Notes: The vertical axes show the percentage deviations from the steady state. The horizontal axes show the anticipation horizon q. The time unit is one quarter. The solid black lines are the response of a three period in advance announced sanction shock. The dashed lines are the responses to an eight period ahead announced sanction news shock. We set $\Omega = 0.10$, $\phi = 0.50$, $\delta_{DE} = 0.08$, and $\rho_v = 0.999$.

Table 4-3 provides the relative variances (σ_f^2) and standard deviations (SD) of doping intensity for different values of the overall doping rate (Ω) and the habit persistence parameter (ϕ) in the case of sanction shocks. The findings confirm the results in the case of technology news in Section 4.3.1.

First, the lower the overall doping prevalence is, denoted by Ω, the lower the dynamics in response to sanction news. Second, the investigation of a low (3%) and a moderate (10%) doping prevalence reveals that the sooner sanction news is announced by the governing body (i.e., the larger q), the larger the reaction during the anticipation period. Thus, the relative variances σ_f^2 and the SDs of the doping intensity increase as the anticipation horizon q increases. Third, for large unreported shares of drug takers ($\Omega \geq 70\%$), the exact opposite is true: the relative variances σ_f^2 and the SDs of the doping intensity decrease as the horizon q increases.

Table 4-3 Relative Variances of Doping Behavior in Response to an (Un)Anticipated Increase in Financial Penalties.

		$\Omega = 0.03$			$\Omega = 0.10$			$\Omega = 0.70$		
		$q = 0$	$q = 3$	$q = 8$	$q = 0$	$q = 3$	$q = 8$	$q = 0$	$q = 3$	$q = 8$
$\phi = 0.33$	σ_f^2	0.0038	0.0039	0.0042	0.1018	0.1018	0.1104	7.8765	7.5637	7.5240
	SD	0.0620	0.0628	0.0648	0.3190	0.3190	0.3322	2.8065	2.7502	2.7430
$\phi = 0.50$	σ_f^2	0.0044	0.0045	0.0048	0.0978	0.1001	0.1061	7.0271	6.8242	6.8020
	SD	0.0662	0.0671	0.0692	0.3127	0.3165	0.3257	2.6509	2.6123	2.6081
$\phi = 0.99$	σ_f^2	0.0064	0.0066	0.0070	0.0853	0.0875	0.0929	5.0030	4.7990	4.7514
	SD	0.0800	0.0811	0.0836	0.2920	0.2959	0.3047	2.2367	2.1907	2.1800

Notes: The table reports the relative variance of doping behavior σ_f^2 in response to a permanent (un)anticipated anti-doping technology shock in the case of a low ($\Omega = 0.03$), moderate ($\Omega = 0.10$) and high ($\Omega = 0.70$) unreported/unofficial share of drug abuse among elite athletes. Parameter ϕ denotes the level of habit formation.

Our simulations indicate that the pure announcement of better testing opportunities or higher monetary sanctions may affect athletes' intention to dope. Consequently, news shocks may have a deterrent effect on potentially doping athletes. From our analysis, it seems reasonable that authorities may consider news shocks as an anti-doping instrument. Moreover, the implementation of new technologies or increased sanctions reduces the use of PESs among athletes in the long term.

4.4 Conclusion

This article develops a dynamic model of delinquency and models the effects of news shocks in prevention policies. Using the case of doping in elite sports, we demonstrate that the pure announcement ("news shock") of a more efficient detection technique or higher fines (in case of detected doping)—several periods before the true implementation—may decrease the rate of delinquent behavior. The immediate and long-run effects are more pronounced in the case of new detection techniques. We conclude that the behavior of potential delinquent persons depends not only on a data set including current perceived values of decision parameters but also on expected future changes in crime prevention conditions.

Overall, in line with studies on "forward guidance" (e.g., Andrade et al., 2019; McKay et al., 2016) our findings support the importance of policy signaling and communication as an additional policy tool to affect agents' incentives since agents adjust their behavior in response to announced changes. Furthermore, we agree with the criminal deterrence literature (e.g., Grogger, 1991; Witte, 1980) that a perceived increase in the certainty of detection is more effective than an increase in the severity of punishments.

4.5 Appendix D. Rearranged Budged Constraint

By inserting equations (4-3) and (4-4) in (4-2), we obtain

$$S_{t+k+1} = a^* S_{t+k} + c^* S_{t+k} N_{t+k} - b^* S_{t+k} N_{t+k} + I_{t+k} \tag{D 1}$$

with the abbreviations

$a^* = 1 - \delta_{SC}$, $b^* = \pi\delta_{DH}$, and $c^* = (1-\pi)\delta_{DE}$

Simplifying equation (D 1) results in

$$S_{t+k+1} = a^* S_{t+k} + (c^* - b^*) S_{t+k} N_{t+k} + I_{t+k} \tag{D 2}$$

By combining equation (D 2) with the budget constraint (equation (4-5))

$$W_{t+k} N_{t+k} + R_{t+k} S_{t+k} = SUC_{t+k} + I_{t+k} + T_{t+k} \tag{4-5}$$

we can eliminate I_{t+k}. Thus, the rearranged budget constraint (D 3) is

$$\begin{aligned} W_{t+k} N_{t+k} + R_{t+k} S_{t+k} + a^* S_{t+k} + (c^* - b^*) S_{t+k} N_{t+k} \\ = SUC_{t+k} + S_{t+k+1} + T_{t+k} \end{aligned} \tag{D 3}$$

4.6 Appendix E. Log-linearized System of Equations

Variables with overbars and without a time index indicate steady state values. Variables with hats represent the percentage deviation from a steady state. Therefore, a first-order Taylor series expansion around the steady state is as follows:

$$\hat{x} = \frac{dX}{\bar{X}} = \frac{1}{\bar{X}}(X - \bar{X}) \approx logX - log\bar{X}$$

4.6.1 Endogenous Equations

The rational expectations equilibrium model is described by the following set of equations.

Sporting production function $\hat{y}$:

$$\hat{y}_t = \alpha \hat{s}_t + (1-\alpha)\hat{j}_t + (1-\alpha)\hat{n}_t \tag{D 4}$$

Sporting capital demand $\hat{r}_t$:

$$\hat{r}_t = \hat{y}_t - \hat{s}_t \tag{D 5}$$

Labor demand $\widehat{w}_t$:

$$\widehat{w}_t = \hat{y}_t - \hat{n}_t \tag{D 6}$$

To enhance the readability, equation (D 7) is solved for $\hat{\lambda}_t$.

An athlete's optimal success path:

$$\hat{\lambda}_t = -\frac{1}{1-\beta\theta}\left(\frac{1}{1-\phi}\widehat{suc}_t - \frac{\phi}{1-\phi}\widehat{suc}_{t-1}\right) + \frac{\beta\theta}{1-\beta\theta}\left(\frac{1}{1-\theta}E_t\widehat{suc}_{t+1} - \frac{\phi}{1-\phi}\widehat{suc}_t\right) \tag{D 7}$$

Labor supply $\hat{n}_t$:

$$\hat{n}_t\bar{N} = \bar{\lambda}\left(\hat{\lambda}_t + \hat{w}_t + (c^* - b^*)\bar{S}\hat{\lambda}_t + (c^* - b^*)\bar{S}\hat{s}_t\right)(1-\bar{N}) \tag{D 8}$$

with

$$\bar{N} = \frac{\theta\bar{G} + (1-\beta\phi)(1-\alpha)h^{*\frac{-\alpha}{1-\alpha}}\bar{J}}{\bar{J}\left[\theta h^{*\frac{-\alpha}{1-\alpha}} - \theta h^{*\frac{-\alpha}{1-\alpha}}d^* + (1-\beta\phi)(1-\alpha)h^{*\frac{-\alpha}{1-\alpha}}\right]} \tag{D 9}$$

where $\bar{G} = e^g, \bar{J} = e^j$, $h^* = -\frac{\frac{1}{\beta} - a^* + (c^* - b^*)}{\alpha}$, and $d^* = 1 - a^* + (b^* - c^*)$.

Lagrangian multiplier $\hat{\lambda}_t$:

$$\hat{\lambda}_t = \beta\left(E_t\hat{\lambda}_{t+1}\bar{R} + \bar{R}E_t\hat{r}_{t+1} + a^*E_t\hat{\lambda}_{t+1} + E_t\hat{\lambda}_{t+1}\frac{1}{\bar{\lambda}}(c^* - b^*)\bar{N} + (c^* - b^*)\bar{N}E_t\hat{n}_{t+1}\right) \tag{D 10}$$

with $\bar{R} = \frac{1}{\beta} - a^*(c^* - b^*)$

Optimal sporting capital formation $\hat{s}_t$:

$$E_t\hat{s}_{t+1} = a^*\hat{s}_t + (c^* - b^*)\bar{N}\hat{s}_t + (c^* - b^*)\bar{N}\hat{n}_t + \frac{1}{\bar{S}}[\bar{Y}\hat{y}_t - \overline{SUC}\widehat{suc}_t - \bar{G}\hat{g}_t] \tag{D 11}$$

where $\bar{S} = h^{*\frac{-1}{1-\alpha}}\bar{J}\bar{N}$, $\bar{Y} = h^*\bar{S}$, and $\overline{SUC} = \bar{Y} - d^*\bar{S} - \bar{G}$.

Expected doping behavior $\hat{\jmath}_t$:

$$E_t\hat{\jmath}_{t+1} = \frac{1}{\bar{J}}[\delta_\Omega\bar{J}\hat{\jmath}_t - \delta_\Omega\bar{J}\bar{\imath}\hat{\jmath}_t - (1-\delta_\Omega)\Omega\bar{\imath}E_t\hat{\imath}_{t+1} - \delta_\Omega\bar{J}\bar{\imath}E_t\hat{\imath}_{t+1}] \tag{D 12}$$

The anti-doping authority's policy constraint

$$\hat{T}_t = \hat{g}_t \tag{D 13}$$

closes our model.

4.6.2 Exogenous Processes

Anti-doping technology shock:

$$\hat{v}_t = \rho_v v_{t-1} + \varepsilon_{t-q}^{v} \tag{D 14}$$

Anti-doping sanction shock:

$$\hat{g}_t = \rho_g g_{t-1} + \varepsilon_{t-q}^{g} \tag{D 15}$$

4.7 References

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